Solaris 10
Performance, Observability and Debugging

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About The Instructors

Richard McDougall, had he lived 100 years ago, would have had the hood open on the first four-stroke internal combustion powered vehicle, exploring new techniques for making improvements. He would be looking for simple ways to solve complex problems and helping pioneering owners understand how the technology worked to get the most from their new experience. these days, McDougall uses technology to satisfy his curiosity. He is a Distinguished Engineer at Sun Microsystems, specializing in operating systems technology and systems performance.

Jim Mauro is a Senior Staff Engineer in Sun's Performance, Architecture and Applications Engineering group, where his most recent efforts have been Solaris performance on Opteron platforms, specifcally in the area of file system and raw disk IO performance. Jim's interests include operating systems scheduling and thread support, threaded applications, file systems and operating system tools for observability. Outside interests include reading and music; Jim proudly keeps his turntable in top working order, and still purchases and plays 12 inch vinyl LPs. Jim lives in New Jersey with his wife and two Sons. When he's not writing or working, he's handling trouble tickets generated by his family on issues they're having with home networking and getting the printer to print.

Richard and Jim authored ***Solaris Internals: Solaris 10 and Open Solaris Kernel Architecture.***
Prentice Hall, 2006. ISBN 0-13-148209-2

Richard and Jim (with Brendan Gregg) authored ***Solaris Performance and Tools: DTrace and MDB Techniques for Solaris 10 and Open Solaris***
Prentice Hall, 2006. ISBN 0-13-156819-1

Richard and Jim authored ***Solaris Internals:Core Kernel Architecture,***
Prentice Hall, 2001. ISBN 0-13-022496-0

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Agenda

- Session 1 - 9:00AM to 10:30PM
  - Goals, non goals and assumptions
  - OpenSolaris
  - Solaris 10 Kernel Overview
  - Solaris 10 Features
  - The Tools of the Trade
- Session 2 - 11:00PM to 12:30PM
  - Memory
    - Virtual Memory
    - Physical Memory
    - Memory dynamics
    - Performance and Observability
    - Memory Resource Management

Agenda

- Session 3 - 2:00PM to 3:30PM
  - > Processes, Threads & Scheduling
    - > Processes, Threads, Priorities & Scheduling
    - > Performance & Observability
      - – Load, apps & the kernel
    - > Processor Controls and Binding
    - > Resource Pools, Projects & Zones
- Session 4 - 4:00PM to 5:30PM
  - > File Systems and I/O
    - > I/O Overview
    - > The Solaris VFS/Vnode Model
    - > UFS – The Solaris Unix File System
    - > Performance & Observability
  - > Network & Miscellanea

Session 1
Intro, Tools, Stuff

Goals, Non-goals & Assumptions

- Goals
  - > Architectural overview of the Solaris kernel
  - > The tools – what they are, what they do, when and how to use them
  - > Correlate performance & observability to key functions
  - > Resource control & management framework
- Non-goals
  - > Detailed look at core kernel algorithms
  - > Networking internals
- Assumptions
  - > General familiarity with the Solaris environment
  - > General familiarity with operating systems concepts

OpenSolaris

- An open source operating system providing for community collaboration and development
- Source code released under the Common Development & Distribution License (CDDL – pronounced “cuddle”)
- Based on “Nevada” Solaris code-base (Solaris 10+)
- Core components initially, other systems will follow over time
  - ZFS!
- Communities, discussion groups, tools, documentation, etc

Why Performance, Observability & Debugging?

- Reality, what a concept
  > Chasing performance problems
    > Sometimes they are even well defined
  > Chasing pathological behaviour
    > My app should be doing X, but it's doing Y
      – It's only doing it sometimes
  > Understand utilization
    > Resource consumption
      – CPU, Memory, IO
    > Capacity planning
  > In general, attaining a good understanding of the system, the workload, and how they interact
- 90% of system activity falls into one of the above categories, for a variety of roles
  > Admins, DBA's, Developers, etc...

Before You Begin...

"Would you tell me, please, which way I ought to go from here?" asked Alice

"*That depends a good deal on where you want to get to*" said the Cat

"*I don't much care where...*" said Alice

"*Then it doesn't matter which way you go*" said the Cat

Lewis Carroll

Alice's Adventures in Wonderland

General Methods & Approaches

- Define the problem
  - In terms of a business metric
  - Something measurable
- System View
  - Resource usage/utilization
    - CPU, Memory, Network, IO
- Process View
  - Execution profile
    - Where's the time being spent
  - May lead to a thread view
- Drill down depends on observations & goals
  - The path to root-cause has many forks
  - “bottlenecks” move
    - Moving to the next knee-in-the-curve

Amdahl's Law

- In general terms, defines the expected speedup of a system when part of the system is improved
- As applied to multiprocessor systems, describes the expected speedup when a unit of work is parallelized
  - Factors in degree of parallelization

$$S=\frac{1}{(F+\frac{(1-F)}{N})}$$

S is the speedup

F is the fraction of the work that is serialized

N is the number of processors

$$S=\frac{1}{(0.5+\frac{(1-0.5)}{4})}$$

S = 1.6 4 processors, ½ of the work is serialized

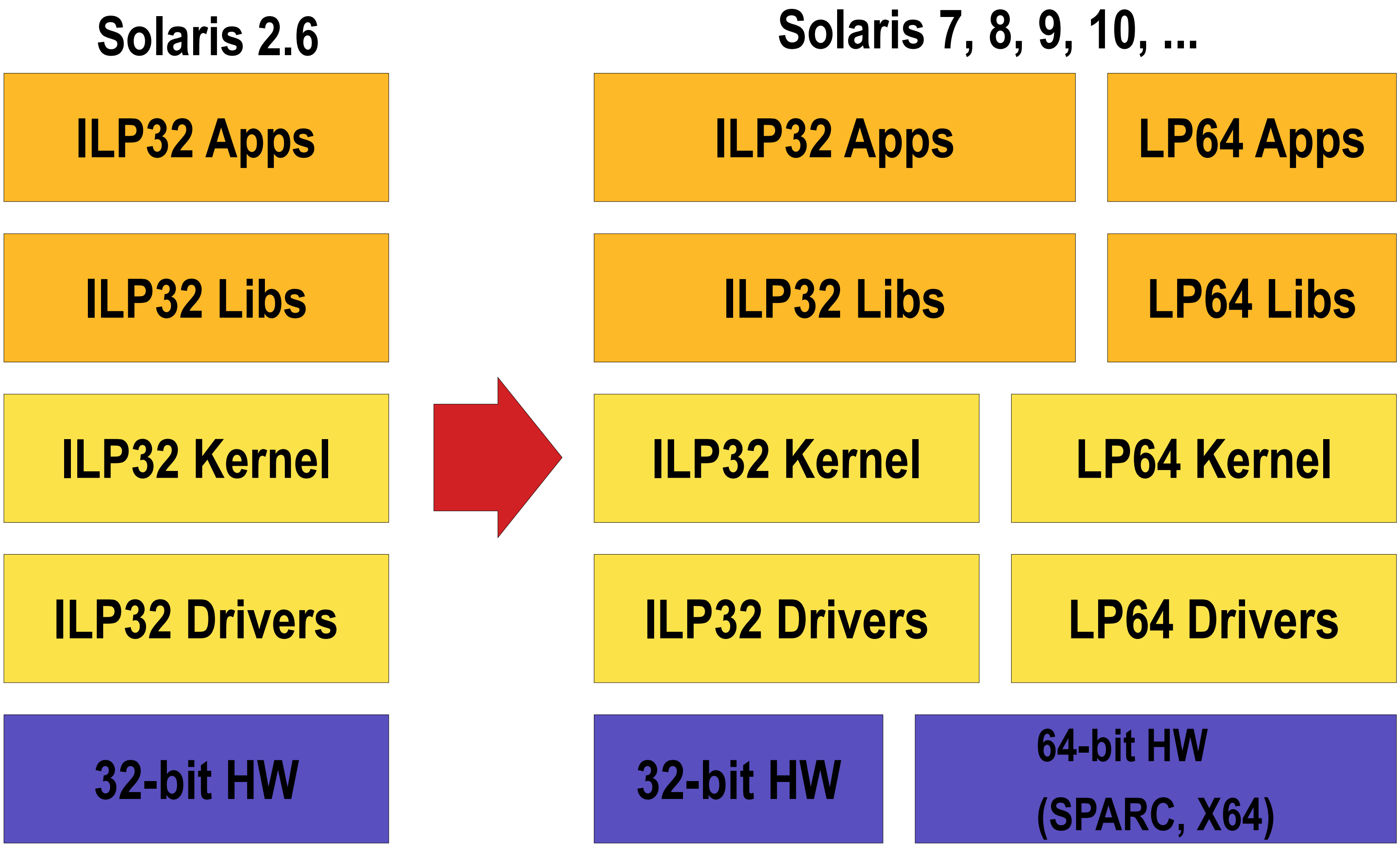
$$S=\frac{1}{(0.25+\frac{(1-0.25)}{4})}$$

S = 2.3 4 processors, ¼ of the work is serialized

Solaris Kernel Features

- Dynamic
- Multithreaded
- Preemptive
- Multithreaded Process Model
- Multiple Scheduling Classes
  - Including realtime support, fixed priority and fair-share scheduling
- Tightly Integrated File System & Virtual Memory
- Virtual File System
- 64-bit kernel
  - 32-bit and 64-bit application support
- Resource Management
- Service Management & Fault Handling
- Integrated Networking

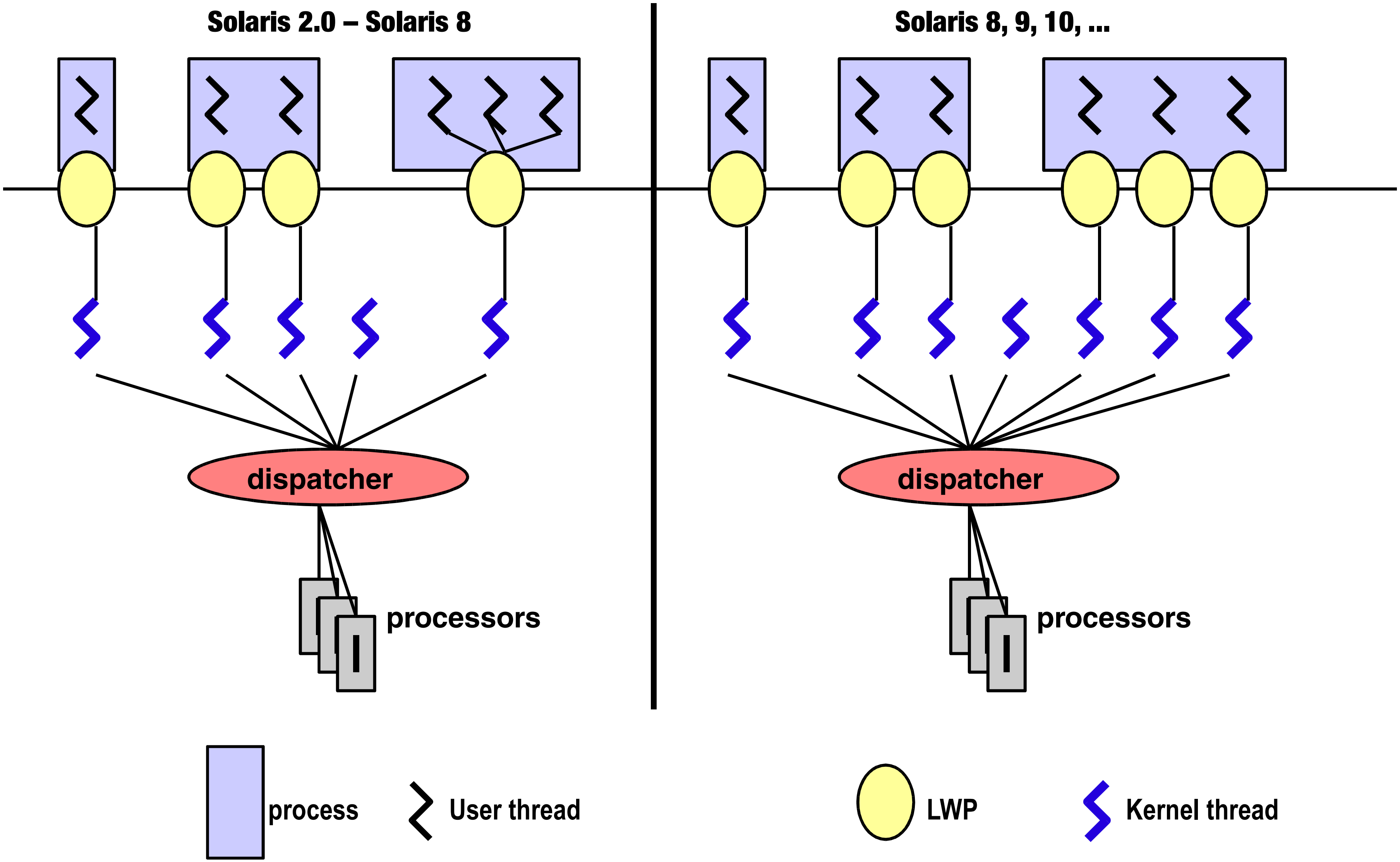
The 64-bit Revolution



Solaris 8 – A Few Selected Highlights

- A new 1:1 threads implementation
  - /usr/lib/lwp/libthread.so
- Page cache enhancements (segmap)
  - Cyclic page cache
- **/dev/poll** for scalable I/O
- Modular debugging with **mdb**(1)
- You want statistics?
  - **kstat**(1M), **prstat**(1M), **lockstat**(1M), **busstat**(1M), **cpustat**(1M), ...
- UFS Direct I/O

Threads Model Evolution



Solaris 9

A Subset of the 300+ New Features

Manageability

- Solaris Containers
- Solaris™ 9 Resource Manager
- IPQoS
- Solaris™ Volume Manager (SVM)
- Soft Disk Partitions
- Filesystem for DBMS
- UFS Snapshots
- Solaris™ Flash
- Solaris™ Live Upgrade 2.0
- Patch Manager
- Product Registry
- Sun ONE DS integration
- Legacy directory proxy
- Secure LDAP client
- Solaris WBEM Services
- Solaris instrumentation
- FRU ID
- Sun™ Management Center

Availability

- Solaris Live Upgrade 2.0
- Dynamic Reconfiguration
- Sun StorEdge™ Traffic Manager Software
- IP Multipathing
- Reconfiguration Coordination Manager
- Driver Fault Injection Framework
- Mobile IP
- Reliable NFS
- TCP timers
- PCI and cPCI hot-swap

Security

- IPSec v4 and v6
- SunScreen Firewall
- Enhanced RBAC
- Kerberos V5
- IKE
- PAM enhancements
- Secure sockets layer (SSL)
- Solaris™ Secure Shell
- Extensible password encryption
- Solaris™ Security Toolkit
- TCP Wrappers
- Kernel and user-level encryption frameworks
- Random number generator
- SmartCard APIs

Scalability

- IPv6
- Thread enhancements
- Memory optimization
  - Advanced page coloring
  - Mem Placement Optimization
  - Multi Page Size Support
- Hotspot JVM tuning
- NFS performance increase
- UFS Direct I/O
- Dynamic System Domains
- Enhanced DNLC
- RSM API
- J2SE™ 1.4 software with 64-bit and IPv6
- NCA enhancements

. . . and more:

- **Compatibility Guarantee**
- **Java Support**
- **Linux Compatibility**
- **Network Services**
- **G11N and Accessibility**
- **GNOME Desktop**

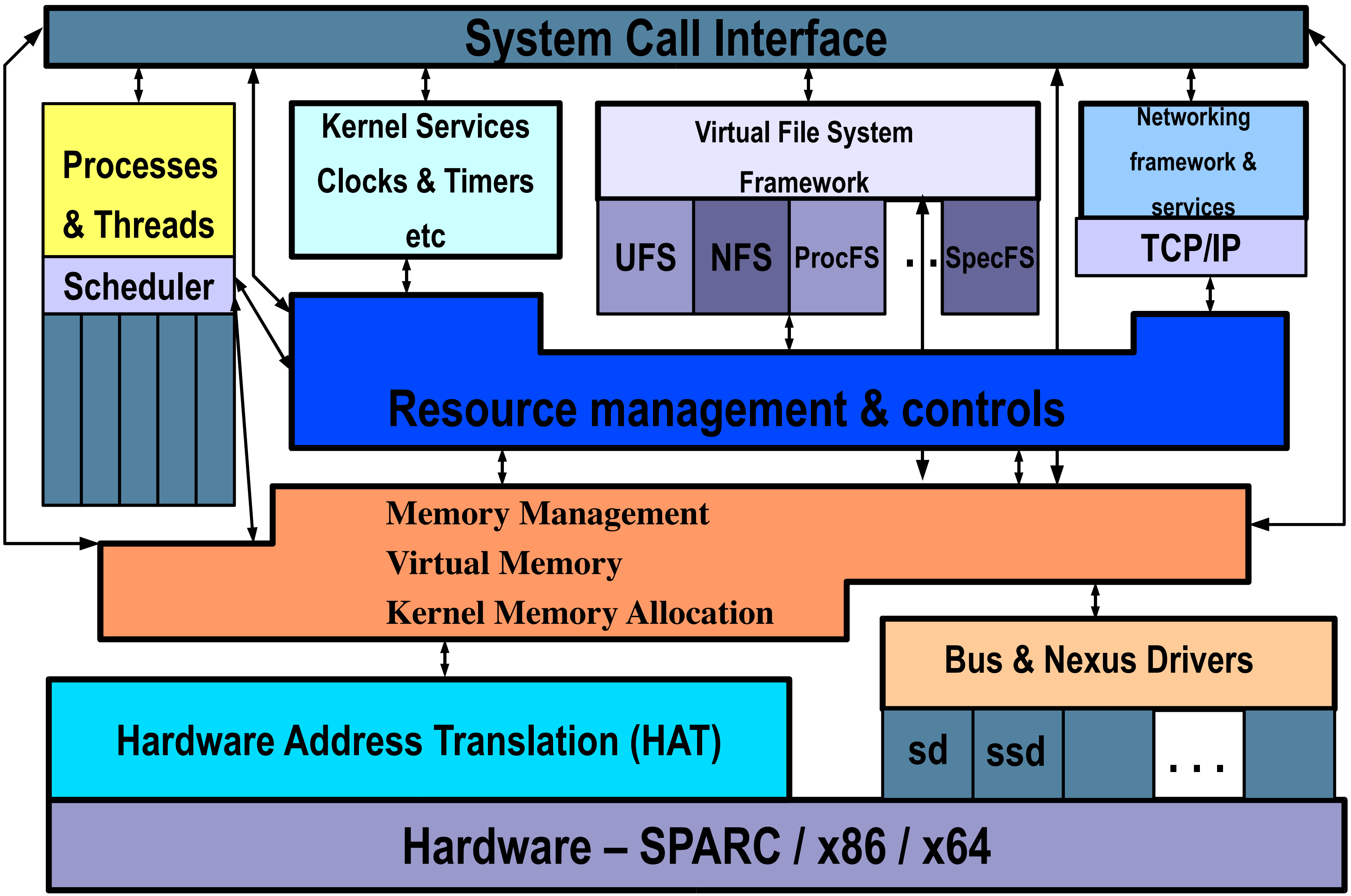
Solaris 10

The Headline Grabbers

- Solaris Containers (Zones)
- Solaris Dynamic Tracing (dtrace)
- Predictive Self Healing
  - > System Management Framework (SMF)
  - > Fault Management Architecture (FMA)
- Process Rights Management
- Premier x86 support
- Optimized 64-bit Opteron support (x64)
- Zetabyte Filesystem (ZFS)

... and much, much more!

Solaris Kernel Overview



Introduction To Performance & Observability Tools

Solaris Performance and Tracing Tools

Process stats

- cputrack - per-processor hw counters
- pargs – process arguments
- pflags – process flags
- pcred – process credentials
- pldd – process's library dependencies
- psig – process signal disposition
- pstack – process stack dump
- pmap – process memory map
- pfiles – open files and names
- prstat – process statistics
- ptree – process tree
- ptime – process microstate times
- pwdx – process working directory

Process control

- pgrep – grep for processes
- pkill – kill processes list
- pstop – stop processes
- prun – start processes
- prctl – view/set process resources
- pwait – wait for process
- preap – reap a zombie process

Process Tracing/ debugging

- abitrace – trace ABI interfaces
- dtrace – trace the world
- mdb – debug/control processes
- truss – trace functions and system calls

Kernel Tracing/ debugging

- dtrace – trace and monitor kernel
- lockstat – monitor locking statistics
- lockstat -k – profile kernel
- mdb – debug live and kernel cores

System Stats

- acctcom – process accounting
- busstat – Bus hardware counters
- cpustat – CPU hardware counters
- iostat – IO & NFS statistics
- kstat – display kernel statistics
- mpstat – processor statistics
- netstat – network statistics
- nfsstat – nfs server stats
- sar – kitchen sink utility
- vmstat – virtual memory stats

Solaris 10 Dynamic Tracing - DTrace

“ [expletive deleted] It's like they saw inside my head and gave me The One True Tool.”

- A Slashdotter, in a post referring to DTrace

“ With DTrace, I can walk into a room of hardened technologists and get them giggling”

- Bryan Cantrill, Inventor of DTrace

DTrace

Solaris Dynamic Tracing – An Observability Revolution

- Seamless, *global* view of the system from user-level thread to kernel
- Not reliant on pre-determined trace points, but *dynamic instrumentation*
- Data *aggregation* at source minimizes postprocessing requirements
- Built for live use on *production* systems

DTrace

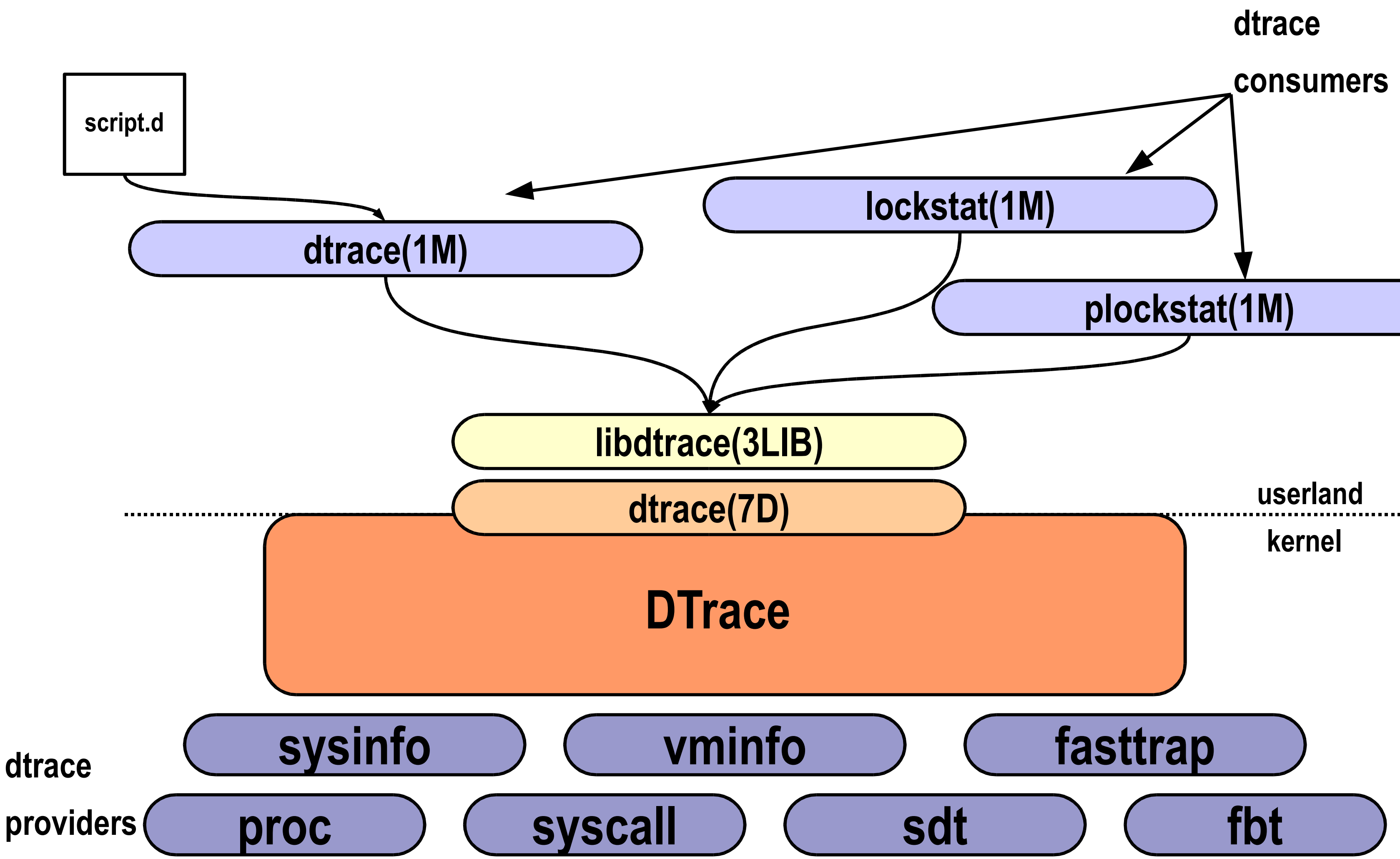
Solaris Dynamic Tracing – An Observability Revolution

- Ease-of-use and *instant gratification* engenders serious *hypothesis testing*
- Instrumentation directed by high-level control language (not unlike AWK or C) for easy scripting and command line use
- Comprehensive probe coverage and powerful data management allow for *concise* answers to *arbitrary* questions

DTrace Components

- Probes
  - A point of instrumentation
  - Has a name (string), and a unique probe ID (integer)
  - *provider:module:function:name*
- Providers
  - DTrace-specific facilities for managing probes, and the interaction of collected data with consumers
- Consumers
  - A process that interacts with dtrace
  - typically `dtrace`(1)
- Using dtrace
  - Command line – `dtrace`(1)
  - Scripts written in the 'D' language

DTrace – The Big Picture



DTrace

- Built-in variables
  - pid, tid, execname, probefunc, timestamp, zoneid, etc
- User defined variables
  - thread local
  - global
  - clause local
  - associative arrays
- All ANSI 'C' Operators
  - Arithmetic, Logical, Relational
- Predicates
  - Conditional expression before taking action
- Aggregations
  - process collected data at the source

DTrace – command line

```
usenix> dtrace -n 'syscall:::entry { @scalls[probefunc] = count() }'
dtrace: description 'syscall:::entry ' matched 228 probes
^C

  lwp_self                                                     1
  fork1                                                        1
  fdsync                                                       1
  sigpending                                                   1
  rexit                                                        1
  fxstat                                                       1
  ...
  write                                                      205
  writev                                                     234
  brk                                                        272
  munmap                                                     357
  mmap                                                       394
  read                                                       652
  pollsys                                                    834
  ioctl                                                     1116
usenix>
```

The D language

- D is a C-like language specific to DTrace, with some constructs similar to awk(1)
- Complete access to kernel C types
- Complete access to statics and globals
- Complete support for ANSI-C operators
- Support for strings as first-class citizen
- We'll introduce D features as we need them...

DTrace – D scripts

```
usenix> cat syscalls_pid.d

#!/usr/sbin/dtrace -s

dtrace:::BEGIN
{
        vtotal = 0;
}

syscall:::entry
/pid == $target/
{
        self->vtime = vtimestamp;
}

syscall:::return
/self->vtime/
{
        @vtime[probefunc] = sum(vtimestamp - self->vtime);
        vtotal += (vtimestamp - self->vtime);
        self->vtime = 0;
}

dtrace:::END
{
        normalize(@vtime, vtotal / 100);
        printa(@vtime);
}
```

a complete dtrace script block, including probename, a predicate, and an action in the probe clause, which sets a thread-local variable

DTrace – Running syscalls_pid.d

```
usenix> ./syscalls_pid.d -c date
dtrace: script './sc.d' matched 458 probes
Sun Feb 20 17:01:28 PST 2005
dtrace: pid 2471 has exited
CPU     ID                    FUNCTION:NAME
  0      2                             :END
  getpid                                                          0
  gtime                                                           0
  sysi86                                                          1
  close                                                           1
  getrlimit                                                       2
  setcontext                                                      2
  fstat64                                                         4
  brk                                                             8
  open                                                            8
  read                                                            9
  munmap                                                          9
  mmap                                                           11
  write                                                          15
  ioctl                                                          24
```

DTrace Providers

- Providers manage groups of probes that are related in some way
- Created as part of the DTrace framework to enable dtracing key subsystems without an intimate knowledge of the kernel
  - **vminfo** – statistics on the VM subsystem
  - **syscall** – entry and return points for all system calls
    - args available at entry probes
  - **sched** – key events in the scheduler
  - **io** – disk IO tracing
  - **sysinfo** – kstats “sys” statistics
  - **mib** – network stack probing
  - **pid** – instrumenting user processes
  - **fbt** – function boundary tracing (kernel functions)
    - args available as named types at entry (args[0] ... args[n])

DTrace Providers (cont)

```
# dtrace -n 'syscall::write:entry { trace(arg2) }'
dtrace: description 'write:entry ' matched 2 probes
CPU     ID                    FUNCTION:NAME
  0   1026                   write:entry             1
  1   1026                   write:entry            53
  1   9290                   write:entry             2
  1   1026                   write:entry            25
  1   9290                   write:entry            17
  1   1026                   write:entry             2
  1   9290                   write:entry             2
  1   1026                   write:entry           450
  1   9290                   write:entry           450
```

```
# dtrace -n 'fbt:ufs:ufs_write:entry { printf("%s\n",stringof(args[0]->v_path)); }'
dtrace: description 'ufs_write:entry ' matched 1 probe
CPU     ID                    FUNCTION:NAME
 13  16779                  ufs_write:entry /etc/svc/repository.db-journal

 13  16779                  ufs_write:entry /etc/svc/repository.db-journal

 13  16779                  ufs_write:entry /etc/svc/repository.db-journal

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 13  16779                  ufs_write:entry /etc/svc/repository.db-journal

 13  16779                  ufs_write:entry /etc/svc/repository.db-journal

 13  16779                  ufs_write:entry /etc/svc/repository.db-journal
```

DTrace Providers (cont)

```
# dtrace -n 'pid221:libc::entry'
dtrace: description 'pid221:libc::entry' matched 2474 probes
CPU     ID                    FUNCTION:NAME
  0  41705           set_parking_flag:entry
  0  41762             setup_schedctl:entry
  0  42128                 __schedctl:entry
  0  41752                 queue_lock:entry
  0  41749              spin_lock_set:entry
  0  41765                no_preempt:entry
  0  41753               queue_unlock:entry
  0  41750            spin_lock_clear:entry
  0  41766                   preempt:entry
  0  41791                 mutex_held:entry
  0  42160               gettimeofday:entry
  0  41807            _cond_timedwait:entry
  0  41508          abstime_to_reltime:entry
  0  42145             __clock_gettime:entry
  0  41803           cond_wait_common:entry
  0  41800            cond_wait_queue:entry
  0  41799           cond_sleep_queue:entry
  0  41949              _save_nv_regs:entry
  0  41752                 queue_lock:entry
  0  41749              spin_lock_set:entry
  0  41765                no_preempt:entry
```

Aggregations

- When trying to understand suboptimal performance, one often looks for *patterns* that point to bottlenecks
- When looking for patterns, one often doesn't want to study each datum – one wishes to *aggregate* the data and look for larger trends
- Traditionally, one has had to use conventional tools (e.g. awk(1), perl(1)) to post-process reams of data
- DTrace supports aggregation of data as a first class operation

Aggregations, cont.

- An *aggregation* is the result of an aggregating function keyed by an arbitrary tuple
- For example, to count all system calls on a system by system call name:

```
dtrace -n 'syscall:::entry \
   { @syscalls[probefunc] = count(); }'
```

- By default, aggregation results are printed when `dtrace`(1M) exits

Aggregations, cont.

- Aggregations need not be named
- Aggregations can be keyed by more than one expression
- For example, to count all ioctl system calls by both executable name and file descriptor:

```
dtrace -n 'syscall::ioctl:entry \
  { @[execname, arg0] = count(); }'
```

Aggregations, cont.

- Some other aggregating functions:
  - avg() - the average of specified expressions
  - min() - the minimum of specified expressions
  - max() - the maximum of specified expressions
  - count() - number of times the probe fired
  - quantize() - power-of-two distribution
  - lquantize() - linear frequency distribution
- For example, distribution of write(2) sizes by executable name:

```
dtrace -n 'syscall::write:entry \
  { @[execname] = quantize(arg2); }'
```

Aggregations

```
# dtrace -n 'syscall::write:entry { @[execname] = quantize(arg2); }'
dtrace: description 'syscall::write:entry ' matched 1 probe
^C
  in.rshd
           value  ------------- Distribution ------------- count
               0 |                                         0
               1 |@@@@@@@@@@                               16
               2 |@@@@                                     6
               4 |@@@                                      4
               8 |                                         0
              16 |@@@@@                                    7
              32 |@@@                                      4
              64 |@@@@@@@@@@@@@@@                          23
             128 |@                                        1
             256 |                                         0

  cat
           value  ------------- Distribution ------------- count
             128 |                                         0
             256 |@@@@@@@@@@@@@@@@@@@@@@@@@@@              2
             512 |                                         0
            1024 |                                         0
            2048 |@@@@@@@@@@@@@                            1
            4096 |                                         0
```

Allowing dtrace for non-root users

- Setting dtrace privileges
- Add a line for the user in `/etc/user_attr`

```
rmc::::defaultpriv=dtrace_kernel,basic,proc_owner,dtrace_proc
```

DTrace

The Solaris Dynamic Tracing Observability Revolution

- Not just for diagnosing problems
- Not just for kernel engineers
- Not just for service personel
- Not just for application developers
- Not just for system administrators
- Serious fun
- Not to be missed!

Modular Debugger - mdb(1)

- Solaris 8 `mdb`(1) replaces `adb`(1) and `crash`(1M)
- Allows for examining a live, running system, as well as post-mortem (dump) analysis
- Solaris 9 `mdb`(1) adds...
  - Extensive support for debugging of processes
  - /etc/crash and adb removed
  - Symbol information via compressed typed data
  - Documentation
- MDB Developers Guide
  - mdb implements a rich API set for writing custom dcmds
  - Provides a framework for kernel code developers to integrate with `mdb`(1)

Modular Debugger - `mdb`(1)

- `mdb`(1) basics
  - 'd' commands (dcmd)
    - ::dcmds -l for a list
    - expression::dcmd
    - e.g. 0x300acde123::ps
  - walkers
    - ::walkers for a list
    - expression::walk <walker_name>
    - e.g. ::walk cpu
  - macros
    - !ls /usr/lib/adb for a list
    - expression$<macro
    - e.g. cpu0$<cpu

Modular Debugger – mdb(1)

- Symbols and typed data
  - address::print (for symbol)
  - address::print <type>
  - e.g. cpu0::print cpu_t
  - cpu_t::sizeof
- Pipelines
  - expression, dcmd or walk can be piped
  - ::walk <walk_name> | ::dcmd
  - e.g. ::walk cpu | ::print cpu_t
  - Link Lists
  - address::list <type> <member>
  - e.g. 0x70002400000::list page_t p_vpnext
- Modules
  - Modules in /usr/lib/mdb, /usr/platform/lib/mdb etc
  - mdb can use adb macros
  - Developer Interface - write your own dcmds and walkers

```
> ::cpuinfo
 ID ADDR         FLG NRUN BSPL PRI RNRN KRNRN SWITCH THREAD       PROC
  0 0000180c000  1b     0    0  37   no    no t-0    30002ec8ca0 threads
  1 30001b78000  1b     0    0  27   no    no t-0    31122698960 threads
  4 30001b7a000  1b     0    0  59   no    no t-0    30ab913cd00 find
  5 30001c18000  1b     0    0  59   no    no t-0    31132397620 sshd
  8 30001c16000  1b     0    0  37   no    no t-0    3112280f020 threads
  9 30001c0e000  1b     0    0  59   no    no t-1    311227632e0 mdb
 12 30001c06000  1b     0    0  -1   no    no t-0    2a100609cc0 (idle)
 13 30001c02000  1b     0    0  27   no    no t-1    300132c5900 threads
> 30001b78000::cpuinfo -v
 ID ADDR         FLG NRUN BSPL PRI RNRN KRNRN SWITCH THREAD       PROC
  1 30001b78000  1b     0    0  -1   no    no t-3    2a100307cc0 (idle)
                  |
       RUNNING <--+
         READY
        EXISTS
        ENABLE

> 30001b78000::cpuinfo -v
 ID ADDR         FLG NRUN BSPL PRI RNRN KRNRN SWITCH THREAD       PROC
  1 30001b78000  1b     0    0  27   no    no t-1    300132c5900 threads
                  |
       RUNNING <--+
         READY
        EXISTS
        ENABLE

> 300132c5900::findstack
stack pointer for thread 300132c5900: 2a1016dd1a1
  000002a1016dd2f1 user_rtt+0x20()
```

mdb(1) & dtrace(1) – Perfect Together

```
# mdb -k
Loading modules: [ unix krtld genunix specfs dtrace ufs sd ip sctp usba fcp fctl nca nfs random sppp
lofs crypto ptm logindmux md isp cpc fcip ipc ]
> ufs_read::nm -f ctype
C Type
int (*)(struct vnode *, struct uio *, int, struct cred *, struct caller_context *)
> ::print -t struct vnode
{
    kmutex_t v_lock {
        void * [1] _opaque
    }
    uint_t v_flag
    uint_t v_count
    void *v_data
    struct vfs *v_vfsp
    struct stdata *v_stream
    enum vtype v_type
    dev_t v_rdev
    struct vfs *v_vfsmountedhere
    struct vnodeops *v_op
    struct page *v_pages
    pgcnt_t v_npages
    ...
    char *v_path
    ...
}
```

```
# dtrace -n 'ufs_read:entry { printf("%s\n",stringof(args[0]->v_path));}'
dtrace: description 'ufs_read:entry ' matched 1 probe
CPU     ID                    FUNCTION:NAME
  1  16777                   ufs_read:entry /usr/bin/cut

  1  16777                   ufs_read:entry /usr/bin/cut

  1  16777                   ufs_read:entry /usr/bin/cut

  1  16777                   ufs_read:entry /usr/bin/cut

  1  16777                   ufs_read:entry /lib/ld.so.1

  1  16777                   ufs_read:entry /lib/ld.so.1
....
```

Kernel Statistics

- Solaris uses a central mechanism for kernel statistics
  - > "kstat"
  - > Kernel providers
    - > raw statistics (c structure)
    - > typed data
    - > classed statistics
  - > Perl and C API
  - > `kstat`(1M) command

```
# kstat -n system_misc
module: unix                            instance: 0
name:   system_misc                     class:    misc

        avenrun_15min                   90
        avenrun_1min                    86
        avenrun_5min                    87
        boot_time                       1020713737
        clk_intr                        2999968
        crtime                          64.1117776
        deficit                         0
        lbolt                           2999968
        ncpus                           2
```

Procfs Tools

- Observability (and control) for active processes through a pseudo file system (/proc)
- Extract interesting bits of information on running processes
- Some commands work on core files as well

`pargs`	`pfiles`
`pflags`	`pstop`
`pcred`	`prun`
`pldd`	`pwait`
`psig`	`ptree`
`pstack`	`ptime`
`pmap`	`preap*`

*why do Harry Cooper & Ben wish they had `preap`?

pflags, pcred, pldd

```
sol8# pflags $$
482764: -ksh
  data model = _ILP32  flags = PR_ORPHAN
  /1:  flags = PR_PCINVAL|PR_ASLEEP [ waitid(0x7,0x0,0xffbff938,0x7) ]
```

```
sol8$ pcred $$
482764: e/r/suid=36413  e/r/sgid=10
  groups: 10 10512 570
```

```
sol8$ pldd $$
482764: -ksh
/usr/lib/libsocket.so.1
/usr/lib/libnsl.so.1
/usr/lib/libc.so.1
/usr/lib/libdl.so.1
/usr/lib/libmp.so.2
```

psig

```
sol8$ psig $$
15481: -zsh
HUP  caught 0
INT  blocked,caught 0
QUIT blocked,ignored
ILL  blocked,default
TRAP blocked,default
ABRT blocked,default
EMT  blocked,default
FPE  blocked,default
KILL default
BUS  blocked,default
SEGV blocked,default
SYS  blocked,default
PIPE blocked,default
ALRM blocked,caught 0
TERM blocked,ignored
USR1 blocked,default
USR2 blocked,default
CLD  caught 0
PWR  blocked,default
WINCH  blocked,caught 0
URG  blocked,default
POLL blocked,default
STOP default
```

pstack

```
sol8$ pstack 5591
5591:  /usr/local/mozilla/mozilla-bin
-----------------  lwp# 1 / thread# 1  --------------------
 fe99a254 poll    (513d530, 4, 18)
 fe8dda58 poll    (513d530, fe8f75a8, 18, 4, 513d530, ffbeed00) + 5c
 fec38414 g_main_poll (18, 0, 0, 27c730, 0, 0) + 30c
 fec37608 g_main_iterate (1, 1, 1, ff2a01d4, ff3e2628, fe4761c9) + 7c0
 fec37e6c g_main_run (27c740, 27c740, 1, fe482b30, 0, 0) + fc
 fee67a84 gtk_main (b7a40, fe482874, 27c720, fe49c9c4, 0, 0) + 1bc
 fe482aa4 ???????? (d6490, fe482a6c, d6490, ff179ee4, 0, ffe)
 fe4e5518 ???????? (db010, fe4e5504, db010, fe4e6640, ffbeeed0, 1cf10)
 00019ae8 ???????? (0, ff1c02b0, 5fca8, 1b364, 100d4, 0)
 0001a4cc main    (0, ffbef144, ffbef14c, 5f320, 0, 0) + 160
 00014a38 _start   (0, 0, 0, 0, 0, 0) + 5c
-----------------  lwp# 2 / thread# 2  --------------------
 fe99a254 poll    (fe1afbd0, 2, 88b8)
 fe8dda58 poll    (fe1afbd0, fe840000, 88b8, 2, fe1afbd0, 568) + 5c
 ff0542d4 ???????? (75778, 2, 3567e0, b97de891, 4151f30, 0)
 ff05449c PR_Poll  (75778, 2, 3567e0, 0, 0, 0) + c
 fe652bac ???????? (75708, 80470007, 7570c, fe8f6000, 0, 0)
 ff13b5f0 Main__8nsThreadPv (f12f8, ff13b5c8, 0, 0, 0, 0) + 28
 ff055778 ???????? (f5588, fe840000, 0, 0, 0, 0)
 fe8e4934 _lwp_start (0, 0, 0, 0, 0, 0)
```

pfiles

```
sol8$ pfiles $$
pfiles $$
15481: -zsh
  Current rlimit: 256 file descriptors
   0: S_IFCHR mode:0620 dev:118,0 ino:459678 uid:36413 gid:7 rdev:24,11
      O_RDWR
   1: S_IFCHR mode:0620 dev:118,0 ino:459678 uid:36413 gid:7 rdev:24,11
  O_RDWR
   2: S_IFCHR mode:0620 dev:118,0 ino:459678 uid:36413 gid:7 rdev:24,11
  O_RDWR
   3: S_IFDOOR mode:0444 dev:250,0 ino:51008 uid:0 gid:0 size:0
  O_RDONLY|O_LARGEFILE FD_CLOEXEC  door to nscd[328]
  10: S_IFCHR mode:0620 dev:118,0 ino:459678 uid:36413 gid:7 rdev:24,11
  O_RDWR|O_LARGEFILE
```

pfiles

```
solaris10> pfiles 26337
26337:  /usr/lib/ssh/sshd
  Current rlimit: 256 file descriptors
   0: S_IFCHR mode:0666 dev:270,0 ino:6815752 uid:0 gid:3 rdev:13,2
      O_RDWR|O_LARGEFILE
      /devices/pseudo/mm@0:null
   1: S_IFCHR mode:0666 dev:270,0 ino:6815752 uid:0 gid:3 rdev:13,2
      O_RDWR|O_LARGEFILE
      /devices/pseudo/mm@0:null
   2: S_IFCHR mode:0666 dev:270,0 ino:6815752 uid:0 gid:3 rdev:13,2
      O_RDWR|O_LARGEFILE
      /devices/pseudo/mm@0:null
   3: S_IFDOOR mode:0444 dev:279,0 ino:59 uid:0 gid:0 size:0
      O_RDONLY|O_LARGEFILE FD_CLOEXEC  door to nscd[93]
      /var/run/name_service_door
   4: S_IFSOCK mode:0666 dev:276,0 ino:36024 uid:0 gid:0 size:0
      O_RDWR|O_NONBLOCK
        SOCK_STREAM
        SO_REUSEADDR,SO_KEEPALIVE,SO_SNDBUF(49152),SO_RCVBUF(49880)
        sockname: AF_INET6 ::ffff:129.154.54.9  port: 22
        peername: AF_INET6 ::ffff:129.150.32.45  port: 52002
   5: S_IFDOOR mode:0644 dev:279,0 ino:55 uid:0 gid:0 size:0
      O_RDONLY FD_CLOEXEC  door to keyserv[179]
      /var/run/rpc_door/rpc_100029.1

....
```

pwdx, pstop, pwait, ptree

```
sol8$ pwdx $$
15481: /home/rmc
```

```
sol8$ pstop $$
[argh!]
```

```
sol8$ pwait 23141
```

```
sol8$ ptree $$
285   /usr/sbin/inetd -ts
  15554 in.rlogind
    15556 -zsh
  15562 ksh
  15657 ptree 15562
```

pgrep

```
sol8$ pgrep -u rmc
481
480
478
482
483
484
.....
```

prstat(1)

- top-like utility to monitor running processes
- Sort on various thresholds (cpu time, RSS, etc)
- Enable system-wide microstate accounting
  - Monitor time spent in each microstate
- Solaris 9 - “projects” and “tasks” aware

```
  PID USERNAME  SIZE   RSS STATE  PRI NICE      TIME  CPU PROCESS/NLWP
 2597 ks130310 4280K 2304K cpu1     0    0   0:01:25  22% imapd/1
29195 bc21502  4808K 4160K sleep   59    0   0:05:26 1.9% imapd/1
 3469 tjobson  6304K 5688K sleep   53    0   0:00:03 1.0% imapd/1
 3988 tja      8480K 7864K sleep   59    0   0:01:53 0.5% imapd/1
 5173 root     2624K 2200K sleep   59    0  11:07:17 0.4% nfsd/18
 2528 root     5328K 3240K sleep   59    0  19:06:20 0.4% automountd/2
  175 root     4152K 3608K sleep   59    0   5:38:27 0.2% ypserv/1
 4795 snoqueen 5288K 4664K sleep   59    0   0:00:19 0.2% imapd/1
 3580 mauroj   4888K 4624K cpu3    49    0   0:00:00 0.2% prstat/1
 1365 bf117072 3448K 2784K sleep   59    0   0:00:01 0.1% imapd/1
 8002 root       23M   23M sleep   59    0   2:07:21 0.1% esd/1
 3598 wabbott  3512K 2840K sleep   59    0   0:00:00 0.1% imapd/1
25937 pdanner  4872K 4232K sleep   59    0   0:00:03 0.1% imapd/1
11130 smalm    5336K 4720K sleep   59    0   0:00:08 0.1% imapd/1
```

truss(1)

- "trace" the system calls of a process/command
- Extended to support user-level APIs (-u, -U)
- Can also be used for profile-like functions (-D, -E)
- Is thread-aware as of Solaris 9 (pid/lwp_id)

```
usenix> truss -c -p 2556
^C
syscall                seconds   calls  errors
read                      .013    1691
pread                     .015    1691
pread64                   .056     846
                      --------  ------   ----
sys totals:               .085    4228      0
usr time:                 .014
elapsed:                 7.030
usenix> truss -D -p 2556
/2:      0.0304 pread(11, "02\0\0\001\0\0\0\n c\0\0".., 256, 0) = 256
/2:      0.0008 read(8, "1ED0C2 I", 4)                          = 4
/2:      0.0005 read(8, " @C9 b @FDD4 EC6", 8)                  = 8
/2:      0.0006 pread(11, "02\0\0\001\0\0\0\n c\0\0".., 256, 0) = 256
/2:      0.0134 pread64(10, "\0\0\0\0\0\0\0\0\0\0\0\0".., 8192, 0x18C8A000) = 8192
/2:      0.0006 pread(11, "02\0\0\001\0\0\0\n c\0\0".., 256, 0) = 256
/2:      0.0005 read(8, "D6 vE5 @", 4)                          = 4
/2:      0.0005 read(8, "E4CA9A -01D7AAA1", 8)                  = 8
/2:      0.0006 pread(11, "02\0\0\001\0\0\0\n c\0\0".., 256, 0) = 256
```

lockstat(1M)

- Provides for kernel lock statistics (mutex locks, reader/writer locks)
- Also serves as a kernel profiling tool
- Use “-i 971” for the interval to avoid collisions with the clock interrupt, and gather fine-grained data

```
#lockstat -i 971 sleep 300 > lockstat.out
```

```
#lockstat -i 971 -I sleep 300 > lockstatI.out
```

Examining Kernel Activity - Kernel Profiling

```
# lockstat -kIi997 sleep 10
Profiling interrupt: 10596 events in 5.314 seconds (1994 events/sec)
Count indv cuml rcnt     nsec CPU+PIL                  Caller
-------------------------------------------------------------------------------
 5122  48%  48% 1.00     1419 cpu[0]                   default_copyout
 1292  12%  61% 1.00     1177 cpu[1]                   splx
 1288  12%  73% 1.00     1118 cpu[1]                   idle
  911   9%  81% 1.00     1169 cpu[1]                   disp_getwork
  695   7%  88% 1.00     1170 cpu[1]                   i_ddi_splhigh
  440   4%  92% 1.00     1163 cpu[1]+11                splx
  414   4%  96% 1.00     1163 cpu[1]+11                i_ddi_splhigh
  254   2%  98% 1.00     1176 cpu[1]+11                disp_getwork
   27   0%  99% 1.00     1349 cpu[0]                   uiomove
   27   0%  99% 1.00     1624 cpu[0]                   bzero
   24   0%  99% 1.00     1205 cpu[0]                   mmrw
   21   0%  99% 1.00     1870 cpu[0]                   (usermode)
    9   0%  99% 1.00     1174 cpu[0]                   xcopyout
    8   0%  99% 1.00      650 cpu[0]                   ktl0
    6   0%  99% 1.00     1220 cpu[0]                   mutex_enter
    5   0%  99% 1.00     1236 cpu[0]                   default_xcopyout
    3   0% 100% 1.00     1383 cpu[0]                   write
    3   0% 100% 1.00     1330 cpu[0]                   getminor
    3   0% 100% 1.00      333 cpu[0]                   utl0
    2   0% 100% 1.00      961 cpu[0]                   mmread
    2   0% 100% 1.00     2000 cpu[0]+10                read_rtc
```

trapstat(1)

- Solaris 9, Solaris 10 (and beyond...)
- Statistics on CPU traps
  - > Very processor architecture specific
- “-t” flag details TLB/TSB miss traps
  - > Extremely useful for determining if large pages will help performance
    - > Solaris 9 Multiple Page Size Support (MPSS)

```
#trapstat -t
cpu m| itlb-miss %tim itsb-miss %tim | dtlb-miss %tim dtsb-miss %tim |%tim
-----+-------------------------------+-------------------------------+----
  0 u|       360  0.0         0  0.0 |       324  0.0         0  0.0 | 0.0
  0 k|        44  0.0         0  0.0 |     21517  1.1       175  0.0 | 1.1
-----+-------------------------------+-------------------------------+----
  1 u|      2680  0.1         0  0.0 |     10538  0.5        12  0.0 | 0.6
  1 k|       111  0.0         0  0.0 |     11932  0.7       196  0.1 | 0.7
-----+-------------------------------+-------------------------------+----
  4 u|      3617  0.2         2  0.0 |     28658  1.3       187  0.0 | 1.5
  4 k|        96  0.0         0  0.0 |     14462  0.8       173  0.1 | 0.8
-----+-------------------------------+-------------------------------+----
  5 u|      2157  0.1         7  0.0 |     16055  0.7      1023  0.2 | 1.0
  5 k|        91  0.0         0  0.0 |     12987  0.7       142  0.0 | 0.7
-----+-------------------------------+-------------------------------+----
  8 u|      1030  0.1         0  0.0 |      2102  0.1         0  0.0 | 0.2
  8 k|       124  0.0         1  0.0 |     11452  0.6        76  0.0 | 0.6
-----+-------------------------------+-------------------------------+----
  9 u|      7739  0.3        15  0.0 |    112351  4.9       664  0.1 | 5.3
  9 k|        78  0.0         3  0.0 |     65578  3.2      2440  0.6 | 3.8
-----+-------------------------------+-------------------------------+----
 12 u|      1398  0.1         5  0.0 |      8603  0.4       146  0.0 | 0.5
 12 k|       156  0.0         4  0.0 |     13471  0.7       216  0.1 | 0.8
-----+-------------------------------+-------------------------------+----
 13 u|       303  0.0         0  0.0 |       346  0.0         0  0.0 | 0.0
 13 k|        10  0.0         0  0.0 |     27234  1.4       153  0.0 | 1.4
=====+===============================+===============================+====
 ttl |     19994  0.1        37  0.0 |    357610  2.1      5603  0.2 | 2.4
```

The *stat Utilities

- `mpstat`(1)
  > System-wide view of CPU activity
- `vmstat`(1)
  > Memory statistics
  > Don't forget “vmstat -p” for per-page type statistics
- `netstat`(1)
  > Network packet rates
  > Use with care – it does induce probe effect
- `iostat`(1)
  > Disk I/O statistics
  > Rates (IOPS), bandwidth, service times
- `sar`(1)
  > The kitchen sink

cputrack(1)

- Gather CPU hardware counters, per process

```
solaris>  cputrack -N 20 -c pic0=DC_access,pic1=DC_miss -p 19849
   time lwp      event      pic0      pic1
  1.007   1       tick  34543793    824363
  1.007   2       tick         0         0
  1.007   3       tick 1001797338   5153245
  1.015   4       tick 976864106   5536858
  1.007   5       tick 1002880440   5217810
  1.017   6       tick 948543113   3731144
  2.007   1       tick  15425817    745468
  2.007   2       tick         0         0
  2.014   3       tick 1002035102   5110169
  2.017   4       tick 976879154   5542155
  2.030   5       tick 1018802136   5283137
  2.033   6       tick 1013933228   4072636
......

solaris> bc -l
824363/34543793
.02386428728310177171
((100-(824363/34543793)))
99.97613571271689822829
```

Applying The Tools - Example

Start with a System View

```
# mpstat 1
CPU minf mjf xcal  intr ithr  csw icsw migr smtx  srw syscl  usr sys  wt idl
  0    0   0  294   329  227  117   60   12 40597    0 245787   10  90   0   0
  1   11   0    0   141    4   73   41   12 37736    0 244729   11  89   0   0
  2    0   0    0   140    2   64   37    1 34046    0 243383   10  90   0   0
  3    0   0    0   130    0   49   32    2 31666    0 243440   10  90   0   0
CPU minf mjf xcal  intr ithr  csw icsw migr smtx  srw syscl  usr sys  wt idl
  0    0   0   16   432  230  149   68   25 42514   25 250163   10  90   0   0
  1    0   0  100   122    5  117   55   26 38418    8 247621   10  90   0   0
  2    0   0  129   103    2  124   53   12 34029   12 244908    9  91   0   0
  3    0   0   24   123    0  110   45    6 30893   18 242016   10  90   0   0
```

- What jumps out at us...
  - Processors a fully utilized, 90% sys
    - Question: Where is the kernel spending time?
  - syscalls-per-second are high
    - Question: What are these system calls, and where are they coming from
  - mutex's per second are high
    - Question: Which mutex locks, and why?

Processor – kernel profile

```
# lockstat -i997 -Ikw sleep 30

Profiling interrupt: 119780 events in 30.034 seconds (3988 events/sec)

Count indv cuml rcnt     nsec CPU+PIL                Hottest Caller
-------------------------------------------------------------------------------
29912  25%  25% 0.00     5461 cpu[2]                 kcopy
29894  25%  50% 0.00     5470 cpu[1]                 kcopy
29876  25%  75% 0.00     5401 cpu[3]                 kcopy
29752  25% 100% 0.00     5020 cpu[0]                 kcopy
  119   0% 100% 0.00     1689 cpu[0]+10              dosoftint
   71   0% 100% 0.00     1730 cpu[0]+11              sleepq_wakeone_chan
   45   0% 100% 0.00     5209 cpu[1]+11              lock_try
   39   0% 100% 0.00     4024 cpu[3]+11              lock_set_spl
   33   0% 100% 0.00     5156 cpu[2]+11              setbackdq
   30   0% 100% 0.00     3790 cpu[3]+2               dosoftint
    6   0% 100% 0.00     5600 cpu[1]+5               ddi_io_getb
    3   0% 100% 0.00     1072 cpu[0]+2               apic_redistribute_compute
-------------------------------------------------------------------------------
# dtrace -n 'profile-997ms / arg0 != 0 / { @ks[stack()]=count() }'
dtrace: description 'profile-997ms ' matched 1 probe
^C

              genunix`syscall_mstate+0x1c7
              unix`sys_syscall32+0xbd
                1

              unix`bzero+0x3
              procfs`pr_read_lwpusage_32+0x2f
              procfs`prread+0x5d
              genunix`fop_read+0x29
              genunix`pread+0x217
              genunix`pread32+0x26
              unix`sys_syscall32+0x101
                1
```

[Continue from previous slide - dtrace stack() aggregation output...]

```
              .....
             unix`kcopy+0x38
             genunix`copyin_nowatch+0x48
             genunix`copyin_args32+0x45
             genunix`syscall_entry+0xcb
             unix`sys_syscall32+0xe1
               1

             unix`sys_syscall32+0xae
               1

             unix`mutex_exit+0x19
             ufs`rdip+0x368
             ufs`ufs_read+0x1a6
             genunix`fop_read+0x29
             genunix`pread64+0x1d7
             unix`sys_syscall32+0x101
               2

             unix`kcopy+0x2c
             genunix`uiomove+0x17f
             ufs`rdip+0x382
             ufs`ufs_read+0x1a6
             genunix`fop_read+0x29
             genunix`pread64+0x1d7
             unix`sys_syscall32+0x101
              13
```

Another Kernel Stack View

```
# lockstat -i997 -Ikws 10 sleep 30

Profiling interrupt: 119800 events in 30.038 seconds (3988 events/sec)

-------------------------------------------------------------------------------
Count indv cuml rcnt     nsec CPU+PIL                Hottest Caller
29919  25%  25% 0.00     5403 cpu[2]                 kcopy

      nsec ------ Time Distribution ------ count     Stack
      1024 |                               2         uiomove
      2048 |                               18        rdip
      4096 |                               25        ufs_read
      8192 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@  29853     fop_read
     16384 |                               21        pread64
                                                     sys_syscall32
-------------------------------------------------------------------------------
Count indv cuml rcnt     nsec CPU+PIL                Hottest Caller
29918  25%  50% 0.00     5386 cpu[1]                 kcopy

      nsec ------ Time Distribution ------ count     Stack
      4096 |                               38        uiomove
      8192 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@  29870     rdip
     16384 |                               10        ufs_read
                                                     fop_read
                                                     pread64
                                                     sys_syscall32
-------------------------------------------------------------------------------
Count indv cuml rcnt     nsec CPU+PIL                Hottest Caller
29893  25%  75% 0.00     5283 cpu[3]                 kcopy

      nsec ------ Time Distribution ------ count     Stack
      1024 |                               140       uiomove
      2048 |                               761       rdip
      4096 |@                              1443      ufs_read
      8192 |@@@@@@@@@@@@@@@@@@@@@@@@@@@    27532     fop_read
     16384 |                               17        pread64
                                                     sys_syscall32
-------------------------------------------------------------------------------
```

Who's Doing What...

```
#prstat -Lmc 10 10 > prstat.out
#cat prstat.out
PID USERNAME USR SYS TRP TFL DFL LCK SLP LAT VCX ICX SCL SIG PROCESS/LWPID
  4448 root       12  44 0.0 0.0 0.0 0.0  43 0.5  2K 460 .1M   0 prstat/1
  4447 root      1.2  11 0.0 0.0 0.0 0.1  14  73  54  65 .2M   0 filebench/27
  4447 root      1.1  10 0.0 0.0 0.0 0.1  15  74  57  52 .2M   0 filebench/29
  4447 root      1.1  10 0.0 0.0 0.1 0.0  15  74  64  53 .2M   0 filebench/19
  4447 root      1.1  10 0.0 0.0 0.0 0.4  14  74  49  55 .2M   0 filebench/7
  4447 root      1.1  10 0.0 0.0 0.0 0.2  14  74  51  44 .2M   0 filebench/17
  4447 root      1.1 9.9 0.0 0.0 0.0 0.3  14  74  48  57 .2M   0 filebench/14
  4447 root      1.1 9.9 0.0 0.0 0.0 0.3  14  74  42  61 .2M   0 filebench/9
  4447 root      1.1 9.8 0.0 0.0 0.0 0.1  15  74  51  49 .2M   0 filebench/25
  4447 root      1.1 9.8 0.0 0.0 0.0 0.0  15  74  60  38 .2M   0 filebench/4
  4447 root      1.1 9.7 0.0 0.0 0.0 0.2  14  75  25  69 .2M   0 filebench/26
  4447 root      1.0 9.7 0.0 0.0 0.1 0.0  15  75  54  46 .2M   0 filebench/12
  4447 root      1.1 9.6 0.0 0.0 0.0 0.3  14  75  40  46 .2M   0 filebench/21
  4447 root      1.1 9.6 0.0 0.0 0.0 0.1  15  75  39  70 .2M   0 filebench/31
  4447 root      1.1 9.6 0.0 0.0 0.1 0.0  15  75  38  75 .2M   0 filebench/22
Total: 59 processes, 218 lwps, load averages: 9.02, 14.30, 10.36
   PID USERNAME USR SYS TRP TFL DFL LCK SLP LAT VCX ICX SCL SIG PROCESS/LWPID
  4447 root      1.3  12 0.0 0.0 0.0 0.0 0.0  86  43  41 .3M   0 filebench/16
  4447 root      1.3  12 0.0 0.0 0.0 0.0 0.0  87  35  46 .3M   0 filebench/14
  4447 root      1.3  12 0.0 0.0 0.0 0.0 0.0  87  36  60 .3M   0 filebench/7
  4447 root      1.3  12 0.0 0.0 0.0 0.0 0.0  87  27  44 .3M   0 filebench/24
  4447 root      1.3  12 0.0 0.0 0.0 0.0 0.0  87  41  61 .3M   0 filebench/3
  4447 root      1.3  12 0.0 0.0 0.0 0.0 0.0  87  38  49 .3M   0 filebench/13
  4447 root      1.3  12 0.0 0.0 0.0 0.0 0.0  87  14  71 .3M   0 filebench/2
  4447 root      1.3  12 0.0 0.0 0.0 0.0 0.0  87  32  57 .3M   0 filebench/19
  4447 root      1.3  12 0.0 0.0 0.0 0.0 0.0  87  31  57 .3M   0 filebench/27
  4447 root      1.3  12 0.0 0.0 0.0 0.0 0.0  87  34  47 .3M   0 filebench/4
  4447 root      1.3  11 0.0 0.0 0.0 0.0 0.0  87  21  74 .3M   0 filebench/26
  4447 root      1.2  11 0.0 0.0 0.0 0.0 0.0  87  42  51 .3M   0 filebench/9
  4447 root      1.3  11 0.0 0.0 0.0 0.0 0.0  87  16  83 .3M   0 filebench/18
  4447 root      1.2  11 0.0 0.0 0.0 0.0 0.0  87  42  47 .3M   0 filebench/33
  4447 root      1.2  11 0.0 0.0 0.0 0.0 0.0  87  15  76 .3M   0 filebench/15
Total: 59 processes, 218 lwps, load averages: 12.54, 14.88, 10.59
```

System Calls – What & Who

```
# dtrace -n 'syscall:::entry { @sc[probefunc]=count() }'
dtrace: description 'syscall:::entry ' matched 228 probes
^C

  fstat                                                         1
  mmap                                                          1
  schedctl                                                      1
  waitsys                                                       1
  recvmsg                                                       2
  sigaction                                                     2
  sysconfig                                                     3
  brk                                                           6
  pset                                                          9
  gtime                                                        16
  lwp_park                                                     20
  p_online                                                     21
  setcontext                                                   29
  write                                                        30
  nanosleep                                                    32
  lwp_sigmask                                                  45
  setitimer                                                    54
  pollsys                                                     118
  ioctl                                                       427
  pread64                                                 1583439
  pread                                                   3166885
  read                                                    3166955
# dtrace -n 'syscall::read:entry { @[execname,pid]=count()}'
dtrace: description 'syscall::read:entry ' matched 1 probe
^C

  sshd                                              4342                3
  Xorg                                               536               36
  filebench                                         4376          2727656
```

smtx – Lock Operations

```
# lockstat sleep 30 > lockstat.locks1
# more lockstat.locks1

Adaptive mutex spin: 3486197 events in 30.031 seconds (116088 events/sec)

Count indv cuml rcnt     spin Lock                   Caller
-------------------------------------------------------------------------------
1499963  43%  43% 0.00       84 pr_pidlock             pr_p_lock+0x29
1101187  32%  75% 0.00       24 0xffffffff810cdec0     pr_p_lock+0x50
285012   8%  83% 0.00       27 0xffffffff827a9858     rdip+0x506
212621   6%  89% 0.00       29 0xffffffff827a9858     rdip+0x134
98531    3%  92% 0.00      103 0xffffffff9321d480     releasef+0x55
92486    3%  94% 0.00       19 0xffffffff8d5c4990     ufs_lockfs_end+0x81
89404    3%  97% 0.00       27 0xffffffff8d5c4990     ufs_lockfs_begin+0x9f
83186    2%  99% 0.00       96 0xffffffff9321d480     getf+0x5d
 6356    0%  99% 0.00      186 0xffffffff810cdec0     clock+0x4e9
 1164    0% 100% 0.00      141 0xffffffff810cdec0     post_syscall+0x352
  294    0% 100% 0.00       11 0xffffffff801a4008     segmap_smapadd+0x77
  279    0% 100% 0.00       11 0xffffffff801a41d0     segmap_getmapflt+0x275
  278    0% 100% 0.00       11 0xffffffff801a48f0     segmap_smapadd+0x77
  276    0% 100% 0.00       11 0xffffffff801a5010     segmap_getmapflt+0x275
  276    0% 100% 0.00       11 0xffffffff801a4008     segmap_getmapflt+0x275
...
Adaptive mutex block: 3328 events in 30.031 seconds (111 events/sec)

Count indv cuml rcnt     nsec Lock                   Caller
-------------------------------------------------------------------------------
 1929  58%  58% 0.00 48944759 pr_pidlock             pr_p_lock+0x29
  263   8%  66% 0.00    47017 0xffffffff810cdec0     pr_p_lock+0x50
  255   8%  74% 0.00 53392369 0xffffffff9321d480     getf+0x5d
  217   7%  80% 0.00    26133 0xffffffff810cdec0     clock+0x4e9
  207   6%  86% 0.00   227146 0xffffffff827a9858     rdip+0x134
  197   6%  92% 0.00    64467 0xffffffff8d5c4990     ufs_lockfs_begin+0x9f
  122   4%  96% 0.00    64664 0xffffffff8d5c4990     ufs_lockfs_end+0x81
  112   3%  99% 0.00   164559 0xffffffff827a9858     rdip+0x506
```

smtx – Lock Operations (cont)

```
Spin lock spin: 3491 events in 30.031 seconds (116 events/sec)

Count indv cuml rcnt     spin Lock                         Caller
-------------------------------------------------------------------------------
 2197  63%  63% 0.00     2151 turnstile_table+0xbd8   disp_lock_enter+0x35
  314   9%  72% 0.00     3129 turnstile_table+0xe28   disp_lock_enter+0x35
  296   8%  80% 0.00     3162 turnstile_table+0x888   disp_lock_enter+0x35
  211   6%  86% 0.00     2032 turnstile_table+0x8a8   disp_lock_enter+0x35
  127   4%  90% 0.00      856 turnstile_table+0x9f8   turnstile_interlock+0x171
  114   3%  93% 0.00      269 turnstile_table+0x9f8   disp_lock_enter+0x35
   44   1%  95% 0.00       90 0xffffffff827f4de0      disp_lock_enter_high+0x13
   37   1%  96% 0.00      581 0xffffffff827f4de0      disp_lock_enter+0x35
...
Thread lock spin: 1104 events in 30.031 seconds (37 events/sec)

Count indv cuml rcnt     spin Lock                         Caller
-------------------------------------------------------------------------------
  487  44%  44% 0.00     1671 turnstile_table+0xbd8   ts_tick+0x26
  219  20%  64% 0.00     1510 turnstile_table+0xbd8   turnstile_block+0x387
   92   8%  72% 0.00     1941 turnstile_table+0x8a8   ts_tick+0x26
   77   7%  79% 0.00     2037 turnstile_table+0xe28   ts_tick+0x26
   74   7%  86% 0.00     2296 turnstile_table+0x888   ts_tick+0x26
   36   3%  89% 0.00      292 cpu[0]+0xf8             ts_tick+0x26
   27   2%  92% 0.00       55 cpu[1]+0xf8             ts_tick+0x26
   11   1%  93% 0.00       26 cpu[3]+0xf8             ts_tick+0x26
   10   1%  94% 0.00       11 cpu[2]+0xf8             post_syscall+0x556
...
```

```
R/W writer blocked by writer: 17 events in 30.031 seconds (1 events/sec)

Count indv cuml rcnt     nsec Lock                         Caller
-------------------------------------------------------------------------------

Count indv cuml rcnt     nsec Lock                         Caller
-------------------------------------------------------------------------------
   17 100% 100% 0.00   465308 0xffffffff831f3be0     ufs_getpage+0x369
-------------------------------------------------------------------------------

R/W writer blocked by readers: 55 events in 30.031 seconds (2 events/sec)

Count indv cuml rcnt     nsec Lock                         Caller
-------------------------------------------------------------------------------
   55 100% 100% 0.00  1232132 0xffffffff831f3be0     ufs_getpage+0x369
-------------------------------------------------------------------------------

R/W reader blocked by writer: 22 events in 30.031 seconds (1 events/sec)

Count indv cuml rcnt     nsec Lock                         Caller
-------------------------------------------------------------------------------
   18  82%  82% 0.00    56339 0xffffffff831f3be0     ufs_getpage+0x369
    4  18% 100% 0.00    45162 0xffffffff831f3be0     ufs_putpages+0x176
-------------------------------------------------------------------------------

R/W reader blocked by write wanted: 47 events in 30.031 seconds (2 events/sec)

Count indv cuml rcnt     nsec Lock                         Caller
-------------------------------------------------------------------------------
   46  98%  98% 0.00   369379 0xffffffff831f3be0     ufs_getpage+0x369
    1   2% 100% 0.00   118455 0xffffffff831f3be0     ufs_putpages+0x176
-------------------------------------------------------------------------------
```

Chasing the hot lock caller...

```
# dtrace -n 'pr_p_lock:entry { @s[stack()]=count() }'
dtrace: description 'pr_p_lock:entry ' matched 1 probe
^C
              procfs`pr_read_lwpusage_32+0x4f
              procfs`prread+0x5d
              genunix`fop_read+0x29
              genunix`pread+0x217
              genunix`pread32+0x26
              unix`sys_syscall32+0x101
         12266066
# dtrace -n 'pr_p_lock:entry { @s[execname]=count() }'
dtrace: description 'pr_p_lock:entry ' matched 1 probe
^C

  filebench                                                      8439499
# pgrep filebench
4485
# dtrace -n 'pid4485:libc:pread:entry { @us[ustack()]=count() }'
dtrace: description 'pid4485:libc:pread:entry ' matched 1 probe
^C
              libc.so.1`pread
              filebench`flowop_endop+0x5b
              filebench`flowoplib_read+0x238
              filebench`flowop_start+0x2b1
              libc.so.1`_thr_setup+0x51
              libc.so.1`_lwp_start
          2084651

              libc.so.1`pread
              filebench`flowop_beginop+0x6a
              filebench`flowoplib_read+0x200
              filebench`flowop_start+0x2b1
              libc.so.1`_thr_setup+0x51
              libc.so.1`_lwp_start
          2084651
```

Icing on the cake...

```
# dtrace -q -n 'ufs_read:entry { printf("UFS Read: %s\n",stringof(args[0]->v_path)); }'
UFS Read: /ufs/largefile1
UFS Read: /ufs/largefile1
UFS Read: /ufs/largefile1
UFS Read: /ufs/largefile1
UFS Read: /ufs/largefile1
UFS Read: /ufs/largefile1
^c

#
#
# dtrace -q -n 'ufs_read:entry { @[execname,stringof(args[0]->v_path)]=count() }'
^C

  filebench                                                    /ufs/largefile1
                        864609
```

Example 2

mpstat(1)

```
solaris10> mpstat 2
CPU minf mjf xcal  intr ithr  csw icsw migr smtx  srw syscl  usr sys  wt idl
  0    3   0   10   345  219   44    0    1    3    0    28    0   0   0  99
  1    3   0    5    39    1   65    1    2    1    0    23    0   0   0 100
  2    3   0    3    25    5   22    1    1    2    0    25    0   1   0  99
  3    3   0    3    19    0   27    1    2    1    0    22    0   0   0  99
CPU minf mjf xcal  intr ithr  csw icsw migr smtx  srw syscl  usr sys  wt idl
  0    4   0 11565 14115  228 7614 1348 2732 3136 1229 255474   10  28   0  61
  1    0   0 10690 14411   54 7620 1564 2546 2900 1182 229899   10  28   0  63
  2    0   0 10508 14682    6 7714 1974 2568 2917 1222 256806   10  29   0  60
  3    0   0 9438 14676    0 7284 1582 2362 2622 1126 249150   10  30   0  60
CPU minf mjf xcal  intr ithr  csw icsw migr smtx  srw syscl  usr sys  wt idl
  0    0   0 11570 14229  224 7608 1278 2749 3218 1251 254971   10  28   0  61
  1    0   0 10838 14410   63 7601 1528 2669 2992 1258 225368   10  28   0  62
  2    0   0 10790 14684    6 7799 2009 2617 3154 1299 231452   10  28   0  62
  3    0   0 9486 14869    0 7484 1738 2397 2761 1175 237387   10  28   0  62
CPU minf mjf xcal  intr ithr  csw icsw migr smtx  srw syscl  usr sys  wt idl
  0    0   0 10016 12580  224 6775 1282 2417 2694  999 269428   10  27   0  63
  1    0   0 9475 12481   49 6427 1365 2229 2490  944 271428   10  26   0  63
  2    0   0 9184 12973    3 6812 1858 2278 2577  985 231898    9  26   0  65
  3    0   0 8403 12849    0 6382 1428 2051 2302  908 239172    9  25   0  66
...
```

prstat(1)

```
  PID USERNAME  SIZE   RSS STATE  PRI NICE      TIME  CPU PROCESS/NLWP
21487 root      603M   87M sleep   29   10   0:01:50  35% filebench/9
21491 morgan   4424K 3900K cpu2    59    0   0:00:00 0.0% prstat/1
  427 root       16M   16M sleep   59    0   0:08:40 0.0% Xorg/1
21280 morgan   2524K 1704K sleep   49    0   0:00:00 0.0% bash/1
21278 morgan   7448K 1888K sleep   59    0   0:00:00 0.0% sshd/1
  489 root       12M 9032K sleep   59    0   0:03:05 0.0% dtgreet/1
21462 root      493M 3064K sleep   59    0   0:00:01 0.0% filebench/2
  209 root     4132K 2968K sleep   59    0   0:00:13 0.0% inetd/4
  208 root     1676K  868K sleep   59    0   0:00:00 0.0% sac/1
  101 root     2124K 1232K sleep   59    0   0:00:00 0.0% syseventd/14
  198 daemon   2468K 1596K sleep   59    0   0:00:00 0.0% statd/1
  113 root     1248K  824K sleep   59    0   0:00:00 0.0% powerd/2
  193 daemon   2424K 1244K sleep   59    0   0:00:00 0.0% rpcbind/1
  360 root     1676K  680K sleep   59    0   0:00:00 0.0% smcboot/1
  217 root     1760K  992K sleep   59    0   0:00:00 0.0% ttymon/1
Total: 48 processes, 160 lwps, load averages: 1.32, 0.83, 0.43
```

prstat(1) – Threads

```
   PID USERNAME  SIZE   RSS STATE  PRI NICE      TIME  CPU PROCESS/LWPID
 21495 root      603M   86M sleep   11   10   0:00:03 2.8% filebench/4
 21495 root      603M   86M sleep    3   10   0:00:03 2.8% filebench/3
 21495 root      603M   86M sleep   22   10   0:00:03 2.8% filebench/7
 21495 root      603M   86M sleep   60   10   0:00:03 2.7% filebench/5
 21495 root      603M   86M cpu1    21   10   0:00:03 2.7% filebench/8
 21495 root      603M   86M sleep   21   10   0:00:03 2.7% filebench/2
 21495 root      603M   86M sleep   12   10   0:00:03 2.7% filebench/9
 21495 root      603M   86M sleep   60   10   0:00:03 2.6% filebench/6
 21462 root      493M 3064K sleep   59    0   0:00:01 0.1% filebench/1
 21497 morgan   4456K 3924K cpu0    59    0   0:00:00 0.0% prstat/1
 21278 morgan   7448K 1888K sleep   59    0   0:00:00 0.0% sshd/1
   427 root       16M   16M sleep   59    0   0:08:40 0.0% Xorg/1
 21280 morgan   2524K 1704K sleep   49    0   0:00:00 0.0% bash/1
   489 root       12M 9032K sleep   59    0   0:03:05 0.0% dtgreet/1
   514 root     3700K 2812K sleep   59    0   0:00:02 0.0% nscd/14
Total: 48 processes, 159 lwps, load averages: 1.25, 0.94, 0.51
```

prstat(1) - Microstates

```
  PID USERNAME USR SYS TRP TFL DFL LCK SLP LAT VCX ICX SCL SIG PROCESS/LWPID
 21495 root     6.1  15 0.0 0.0 0.0  51  26 1.9 11K  4K .7M   0 filebench/7
 21495 root     5.7  14 0.0 0.0 0.0  53  26 1.7  9K  4K .6M   0 filebench/3
 21495 root     5.4  13 0.1 0.0 0.0  54  26 1.8 10K  4K .6M   0 filebench/5
 21495 root     5.2  13 0.0 0.0 0.0  54  26 1.8  9K  4K .6M   0 filebench/4
 21495 root     5.2  13 0.0 0.0 0.0  55  26 1.7  9K  4K .6M   0 filebench/6
 21495 root     4.7  12 0.0 0.0 0.0  56  25 1.8  9K  4K .5M   0 filebench/9
 21495 root     4.4  11 0.0 0.0 0.0  57  26 1.6  8K  3K .5M   0 filebench/8
 21495 root     4.1  11 0.0 0.0 0.0  58  26 1.6  7K  3K .4M   0 filebench/2
 21499 morgan   0.0 0.1 0.0 0.0 0.0 0.0 100 0.0  17   2 311   0 prstat/1
   427 root     0.0 0.0 0.0 0.0 0.0 0.0 100 0.0  18   4  72   9 Xorg/1
   489 root     0.0 0.0 0.0 0.0 0.0 0.0 100 0.0  26   1  45   0 dtgreet/1
   471 root     0.0 0.0 0.0 0.0 0.0 0.0 100 0.0   2   2   6   0 snmpd/1
     7 root     0.0 0.0 0.0 0.0 0.0 0.0 100 0.0  15   0   5   0 svc.startd/6
 21462 root     0.0 0.0 0.0 0.0 0.0 0.0 100 0.0  13   0   5   0 filebench/2
   514 root     0.0 0.0 0.0 0.0 0.0 0.0 100 0.0  15   0  47   0 nscd/23
Total: 48 processes, 159 lwps, load averages: 1.46, 1.03, 0.56
```

DTrace – Getting Below The Numbers - syscalls

```
solaris10> mpstat 2
CPU minf mjf xcal  intr ithr  csw icsw migr smtx  srw syscl  usr sys  wt idl
  0    0   0 15078 18098  223 10562 3172 3982 3134 1848 187661    9  35   0  56
  1    0   0 13448 16972   61 8849 1539 3407 2931 1777 231317   10  36   0  54
  2    0   0 12031 17263    6 8695 1467 3325 2854 1738 241761   11  34   0  55
  3    0   0 11051 17694    1 8399 1509 3096 2546 1695 248747   10  35   0  55
^C
solaris10> dtrace -n 'syscall:::entry { @[probefunc]=count() }'
dtrace: description 'syscall:::entry ' matched 229 probes
^C

  . . . .
  yield                                                              2991
  unlink                                                             3586
  xstat                                                              3588
  write                                                              4212
  open64                                                            10762
  close                                                             10762
  llseek                                                            11374
  read                                                              21543
  pread                                                             78918
  lwp_mutex_timedlock                                              578710
  lwp_mutex_unlock                                                 578711
```

Dtrace – Getting Below The Numbers xcalls

```
# dtrace -n 'xcalls { @[probefunc] = count() }'
dtrace: description 'xcalls ' matched 3 probes
^C
  send_one_mondo                                              346343
#
```

```
# cat xcalls.d
#!/usr/sbin/dtrace -s

send_one_mondo:xcalls
{
        @s[stack(20)] = count();
}

END
{
        printa(@s);
}
#
```

Dtrace - xcalls

```
SUNW,UltraSPARC-II`send_one_mondo+0x20
              SUNW,UltraSPARC-II`send_mondo_set+0x1c
              unix`xt_some+0xc4
              unix`xt_sync+0x3c
              unix`hat_unload_callback+0x6ec
              unix`bp_mapout+0x74
              genunix`biowait+0xb0
              ufs`ufs_putapage+0x3f4
              ufs`ufs_putpages+0x2a4
              genunix`segmap_release+0x300
              ufs`ufs_dirremove+0x638
              ufs`ufs_remove+0x150
              genunix`vn_removeat+0x264
              genunix`unlink+0xc
              unix`syscall_trap+0xac
           17024

              SUNW,UltraSPARC-II`send_one_mondo+0x20
              SUNW,UltraSPARC-II`send_mondo_set+0x1c
              unix`xt_some+0xc4
              unix`sfmmu_tlb_range_demap+0x190
              unix`hat_unload_callback+0x6d4
              unix`bp_mapout+0x74
              genunix`biowait+0xb0
              ufs`ufs_putapage+0x3f4
              ufs`ufs_putpages+0x2a4
              genunix`segmap_release+0x300
              ufs`ufs_dirremove+0x638
              ufs`ufs_remove+0x150
              genunix`vn_removeat+0x264
              genunix`unlink+0xc
              unix`syscall_trap+0xac
           17025
```

lockstat(1M)

- Provides for kernel lock statistics (mutex locks, reader/writer locks)
- Also serves as a kernel profiling tool
- Use “-i 971” for the interval to avoid collisions with the clock interrupt, and gather fine-grained data

```
#lockstat -i 971 sleep 300 > lockstat.out

#lockstat -i 971 -I sleep 300 > lockstatI.out
```

Lock Statistics – mpstat

```
# mpstat 1
CPU minf mjf xcal  intr ithr  csw icsw migr smtx  srw syscl  usr sys  wt idl
  8    0   0 6611  456  300 1637    7   26 1110    0   135   33  45   2  21
  9    1   0 1294  250  100 2156    3   29 1659    0    68    9  63   0  28
 10    0   0 3232  308  100 2357    2   36 1893    0   104    2  66   2  30
 11    0   0  647  385  100 1952    1   19 1418    0    21    4  83   0  13
 12    0   0  190  225  100  307    0    1  589    0     0    0  98   0   2
 13    0   0  624  373  100 1689    2   14 1175    0    87    7  80   2  12
 14    0   0  392  312  100 1810    1   12 1302    0    49    2  80   2  15
 15    0   0  146  341  100 2586    2   13 1676    0     8    0  82   1  17
 16    0   0  382  355  100 1968    2    7 1628    0     4    0  88   0  12
. . . .
 23    0   2  555  193  100 1827    2   23 1148    0   288    7  64   7  22
 24    0   0  811  245  113 1327    2   23 1228    0   110    3  76   4  17
 25    0   0  105  500  100 2369    0   11 1736    0     6    0  88   0  11
 26    0   0  163  395  131 2383    2   16 1487    0    64    2  79   1  18
 27    0   1  718 1278 1051 2073    4   23 1311    0   237    9  67   6  19
 28    0   0  868  271  100 2287    4   27 1309    0   139    9  55   0  36
 29    0   0  931  302  103 2480    3   29 1569    0   165    9  66   2  23
 30    0   0 2800  303  100 2146    2   13 1266    0   152   11  70   3  16
 31    0   1 1778  320  100 2368    2   24 1381    0   261   11  56   5  28
```

Examining Adaptive Locks - Excessive Spinning

```
# lockstat sleep 10
Adaptive mutex spin: 293311 events in 10.015 seconds (29288 events/sec)
Count indv cuml rcnt     spin Lock                          Caller
------------------------------------------------------------------------------
218549 75%  75% 1.00     3337 0x71ca3f50                    entersq+0x314
26297   9%  83% 1.00     2533 0x71ca3f50                    putnext+0x104
19875   7%  90% 1.00     4074 0x71ca3f50                    strlock+0x534
14112   5%  95% 1.00     3577 0x71ca3f50                    qcallbwrapper+0x274
 2696   1%  96% 1.00     3298 0x71ca51d4                    putnext+0x50
 1821   1%  97% 1.00       59 0x71c9dc40                    putnext+0xa0
 1693   1%  97% 1.00     2973 0x71ca3f50                    qdrain_syncq+0x160
  683   0%  97% 1.00       66 0x71c9dc00                    putnext+0xa0
  678   0%  98% 1.00       55 0x71c9dc80                    putnext+0xa0
  586   0%  98% 1.00       25 0x71c9ddc0                    putnext+0xa0
  513   0%  98% 1.00       42 0x71c9dd00                    putnext+0xa0
  507   0%  98% 1.00       28 0x71c9dd80                    putnext+0xa0
  407   0%  98% 1.00       42 0x71c9dd40                    putnext+0xa0
  349   0%  98% 1.00     4085 0x8bfd7e1c                    putnext+0x50
  264   0%  99% 1.00       44 0x71c9dcc0                    putnext+0xa0
  187   0%  99% 1.00       12 0x908a3d90                    putnext+0x454
  183   0%  99% 1.00     2975 0x71ca3f50                    putnext+0x45c
  170   0%  99% 1.00     4571 0x8b77e504                    strwsrv+0x10
  168   0%  99% 1.00     4501 0x8dea766c                    strwsrv+0x10
  154   0%  99% 1.00     3773 0x924df554                    strwsrv+0x10
```

Examining Adaptive Locks - Excessing Blocking

```
Adaptive mutex block: 2818 events in 10.015 seconds (281 events/sec)

Count indv cuml rcnt     nsec Lock                   Caller
-------------------------------------------------------------------------------
 2134  76%  76% 1.00  1423591 0x71ca3f50             entersq+0x314
  272  10%  85% 1.00   893097 0x71ca3f50             strlock+0x534
  152   5%  91% 1.00   753279 0x71ca3f50             putnext+0x104
  134   5%  96% 1.00   654330 0x71ca3f50             qcallbwrapper+0x274
   65   2%  98% 1.00   872630 0x71ca51d4             putnext+0x50
    9   0%  98% 1.00   260444 0x71ca3f50             qdrain_syncq+0x160
    7   0%  98% 1.00  1390807 0x8dea766c             strwsrv+0x10
    6   0%  99% 1.00   906048 0x88876094             strwsrv+0x10
    5   0%  99% 1.00  2266267 0x8bfd7e1c             putnext+0x50
    4   0%  99% 1.00   468550 0x924df554             strwsrv+0x10
    3   0%  99% 1.00   834125 0x8dea766c             cv_wait_sig+0x198
    2   0%  99% 1.00   759290 0x71ca3f50             drain_syncq+0x380
    2   0%  99% 1.00  1906397 0x8b77e504             cv_wait_sig+0x198
    2   0%  99% 1.00   645358 0x71dd69e4             qdrain_syncq+0xa0
```

Examining Spin Locks - Excessing Spinning

```
Spin lock spin: 52335 events in 10.015 seconds (5226 events/sec)

Count indv cuml rcnt     spin Lock                   Caller
-------------------------------------------------------------------------------
23531  45%  45% 1.00     4352 turnstile_table+0x79c  turnstile_lookup+0x48
 1864   4%  49% 1.00       71 cpu[19]+0x40           disp+0x90
 1420   3%  51% 1.00       74 cpu[18]+0x40           disp+0x90
 1228   2%  54% 1.00       23 cpu[10]+0x40           disp+0x90
 1159   2%  56% 1.00       60 cpu[16]+0x40           disp+0x90
 1138   2%  58% 1.00       22 cpu[24]+0x40           disp+0x90
 1108   2%  60% 1.00       57 cpu[17]+0x40           disp+0x90
 1082   2%  62% 1.00       24 cpu[11]+0x40           disp+0x90
 1039   2%  64% 1.00       25 cpu[29]+0x40           disp+0x90
 1009   2%  66% 1.00       17 cpu[23]+0x40           disp+0x90
 1007   2%  68% 1.00       21 cpu[31]+0x40           disp+0x90
  882   2%  70% 1.00       29 cpu[13]+0x40           disp+0x90
  846   2%  71% 1.00       25 cpu[28]+0x40           disp+0x90
  833   2%  73% 1.00       27 cpu[30]+0x40           disp+0x90
```

Examining Reader/Writer Locks- Excessing Blocking

```
R/W writer blocked by writer: 1 events in 10.015 seconds (0 events/sec)

Count indv cuml rcnt     nsec Lock                         Caller
-------------------------------------------------------------------------------
    1 100% 100% 1.00   169634 0x9d42d620                   segvn_pagelock+0x150
-------------------------------------------------------------------------------

R/W reader blocked by writer: 3 events in 10.015 seconds (0 events/sec)

Count indv cuml rcnt     nsec Lock                         Caller
-------------------------------------------------------------------------------
    3 100% 100% 1.00  1841415 0x75b7abec                   mir_wsrv+0x18
-------------------------------------------------------------------------------
```

Examining Kernel Activity - Kernel Profiling

```
# lockstat -kIi997 sleep 10
Profiling interrupt: 10596 events in 5.314 seconds (1994 events/sec)
Count indv cuml rcnt     nsec CPU+PIL                Caller
-------------------------------------------------------------------------------
 5122  48%  48% 1.00     1419 cpu[0]                 default_copyout
 1292  12%  61% 1.00     1177 cpu[1]                 splx
 1288  12%  73% 1.00     1118 cpu[1]                 idle
  911   9%  81% 1.00     1169 cpu[1]                 disp_getwork
  695   7%  88% 1.00     1170 cpu[1]                 i_ddi_splhigh
  440   4%  92% 1.00     1163 cpu[1]+11              splx
  414   4%  96% 1.00     1163 cpu[1]+11              i_ddi_splhigh
  254   2%  98% 1.00     1176 cpu[1]+11              disp_getwork
   27   0%  99% 1.00     1349 cpu[0]                 uiomove
   27   0%  99% 1.00     1624 cpu[0]                 bzero
   24   0%  99% 1.00     1205 cpu[0]                 mmrw
   21   0%  99% 1.00     1870 cpu[0]                 (usermode)
    9   0%  99% 1.00     1174 cpu[0]                 xcopyout
    8   0%  99% 1.00      650 cpu[0]                 ktl0
    6   0%  99% 1.00     1220 cpu[0]                 mutex_enter
    5   0%  99% 1.00     1236 cpu[0]                 default_xcopyout
    3   0% 100% 1.00     1383 cpu[0]                 write
    3   0% 100% 1.00     1330 cpu[0]                 getminor
    3   0% 100% 1.00      333 cpu[0]                 utl0
    2   0% 100% 1.00      961 cpu[0]                 mmread
    2   0% 100% 1.00     2000 cpu[0]+10              read_rtc
```

Session 2 - Memory

Virtual Memory

- Simple programming model/abstraction
- Fault Isolation
- Security
- Management of Physical Memory
- Sharing of Memory Objects
- Caching

Solaris Virtual Memory

- Overview
- Internal Architecture
- Memory Allocation
- Paging Dynamics
- Swap Implementation & Sizing
- Kernel Memory Allocation
- SPARC MMU Overview
- Memory Analysis Tools

Solaris Virtual Memory Glossary

Address Space	Linear memory range visible to a program, that the instructions of the program can directly load and store. Each Solaris process has an address space; the Solaris kernel also has its own address space.
Virtual Memory	Illusion of real memory within an address space.
Physical Memory	Real memory (e.g. RAM)
Mapping	A memory relationship between the address space and an object managed by the virtual memory system.
Segment	A co-managed set of similar mappings within an address space.
Text Mapping	The mapping containing the program's instructions and read-only objects.
Data Mapping	The mapping containing the program's initialized data
Heap	A mapping used to contain the program's heap (malloc'd) space
Stack	A mapping used to hold the program's stack
Page	A linear chunk of memory managed by the virtual memory system
VNODE	A file-system independent file object within the Solaris kernel
Backing Store	The storage medium used to hold a page of virtual memory while it is not backed by physical memory
Paging	The action of moving a page to or from its backing store
Swapping	The action of swapping an entire address space to/from the swap device
Swap Space	A storage device used as the backing store for anonymous pages.

Solaris Virtual Memory Glossary (cont)

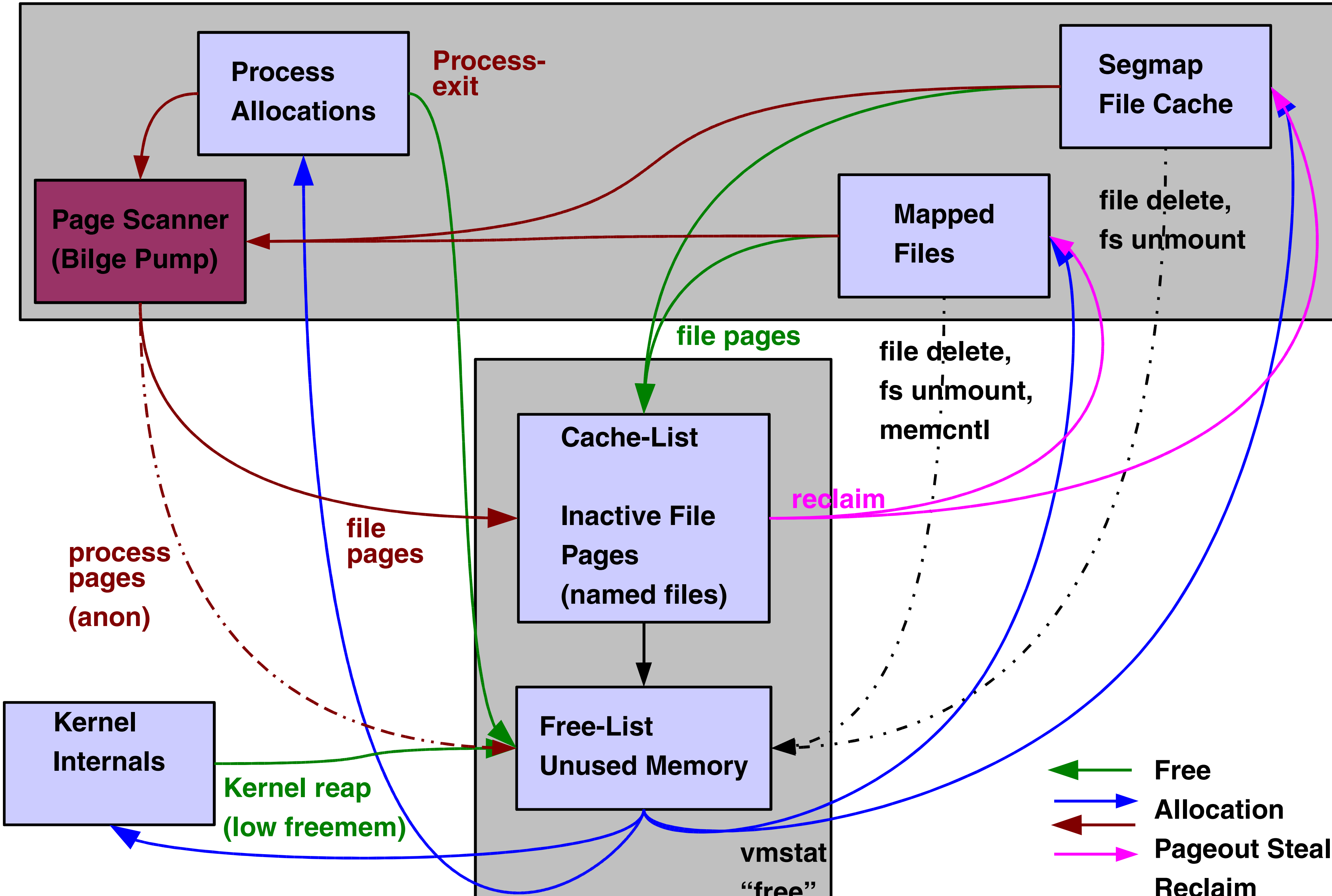
Scanning	The action of the virtual memory system takes when looking for memory which can be freed up for use by other subsystems.
Named Pages	Pages which are mappings of an object in the file system.
Anonymous Memory	Pages which do not have a named backing store
Protection	A set of booleans to describe if a program is allowed to read, write or execute instructions within a page or mapping.
ISM	Intimate Shared Memory - A type of System V shared memory optimized for sharing between many processes
DISM	Pageable ISM
NUMA	Non-uniform memory architecture - a term used to describe a machine with differing processor-memory latencies.
Lgroup	A locality group - a grouping of processors and physical memory which share similar memory latencies
MMU	The hardware functional unit in the microprocessor used to dynamically translate virtual addresses into physical addresses.
HAT	The Hardware Address Translation Layer - the Solaris layer which manages the translation of virtual addresses to physical addresses
TTE	Translation Table Entry - The UltraSPARC hardware's table entry which holds the data for virtual to physical translation
TLB	Translation Lookaside Buffer - the hardware's cache of virtual address translations
Page Size	The translation size for each entry in the TLB
TSB	Translation Software Buffer - UltraSPARC's software cache of TTEs, used for lookup when a translation is not found in the TLB

Solaris Virtual Memory

- Demand Paged, Globally Managed
- Integrated file caching
- Layered to allow virtual memory to describe multiple memory types (Physical memory, frame buffers)
- Layered to allow multiple MMU architectures

Physical Memory Management

Memory Allocation Transitions

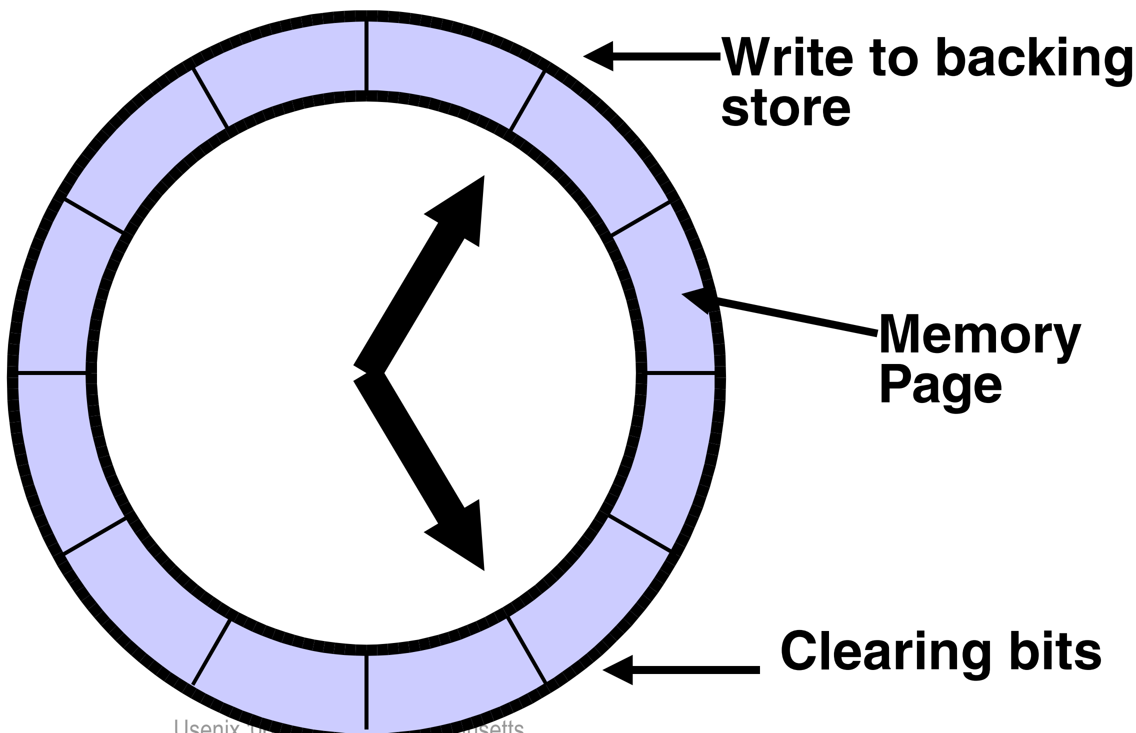


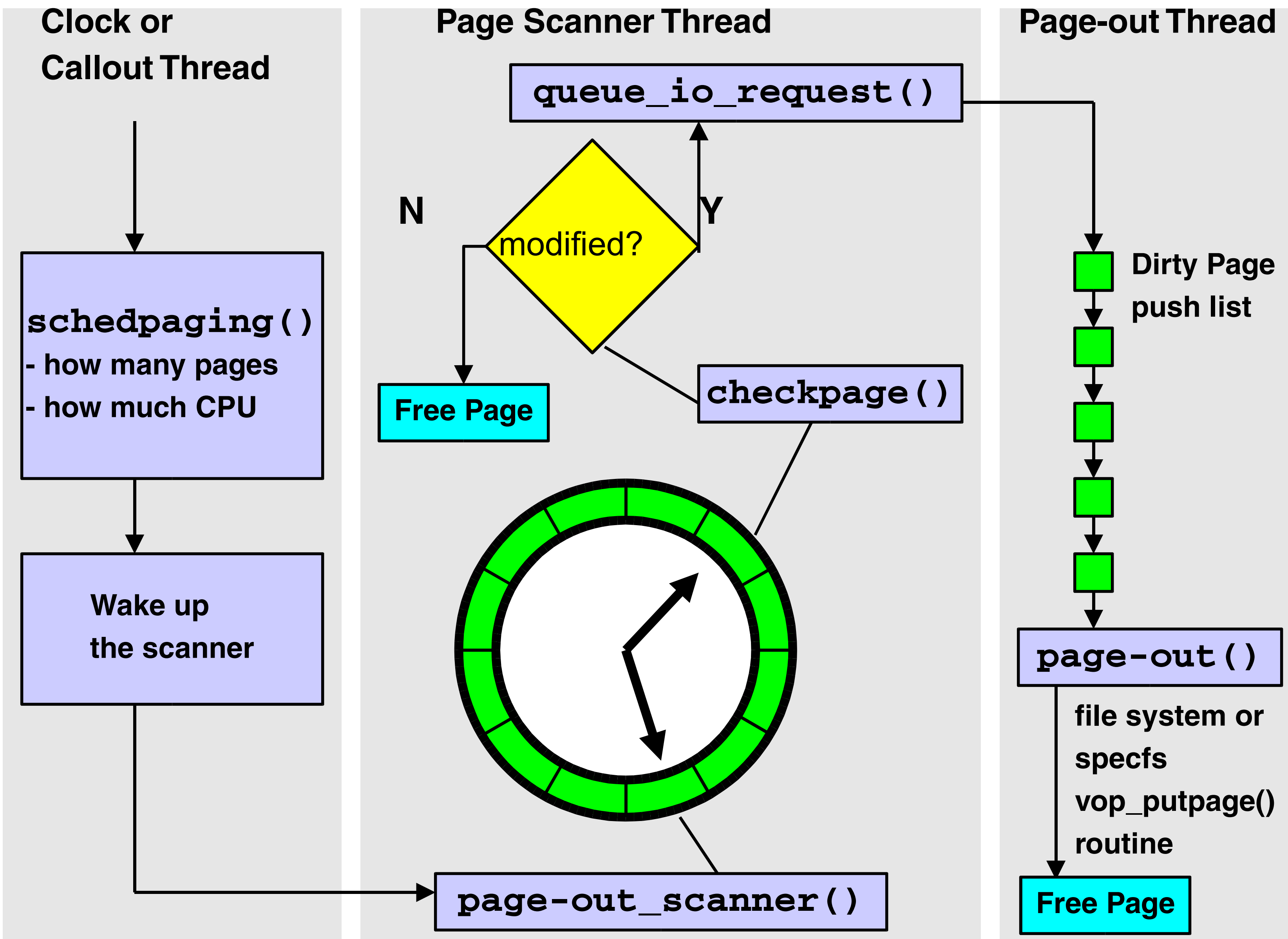
Page Lists

- Free List
  - does not have a vnode/offset associated
  - put on list at process exit.
  - may be always small (pre Solaris 8)
- Cache List
  - still have a vnode/offset
  - seg_map free-behind and seg_vn executables and libraries (for reuse)
  - reclaims are in **`vmstat`** "re"
- Sum of these two are in **`vmstat`** "free"

Page Scanning

- Steals pages when memory is low
- Uses a Least Recently Used process.
- Puts memory out to "backing store"
- Kernel thread does the scanning




Clock or
Callout Thread
Page Scanner Thread
Page-out Thread
queue_io_request()
N
modified?
Y
Dirty Page
push list
schedpaging()
- how many pages
- how much CPU
Free Page
checkpage()
Wake up
the scanner
page-out()
file system or
specfs
vop_putpage()
routine
Free Page
page-out_scanner()

Scanning Algorithm

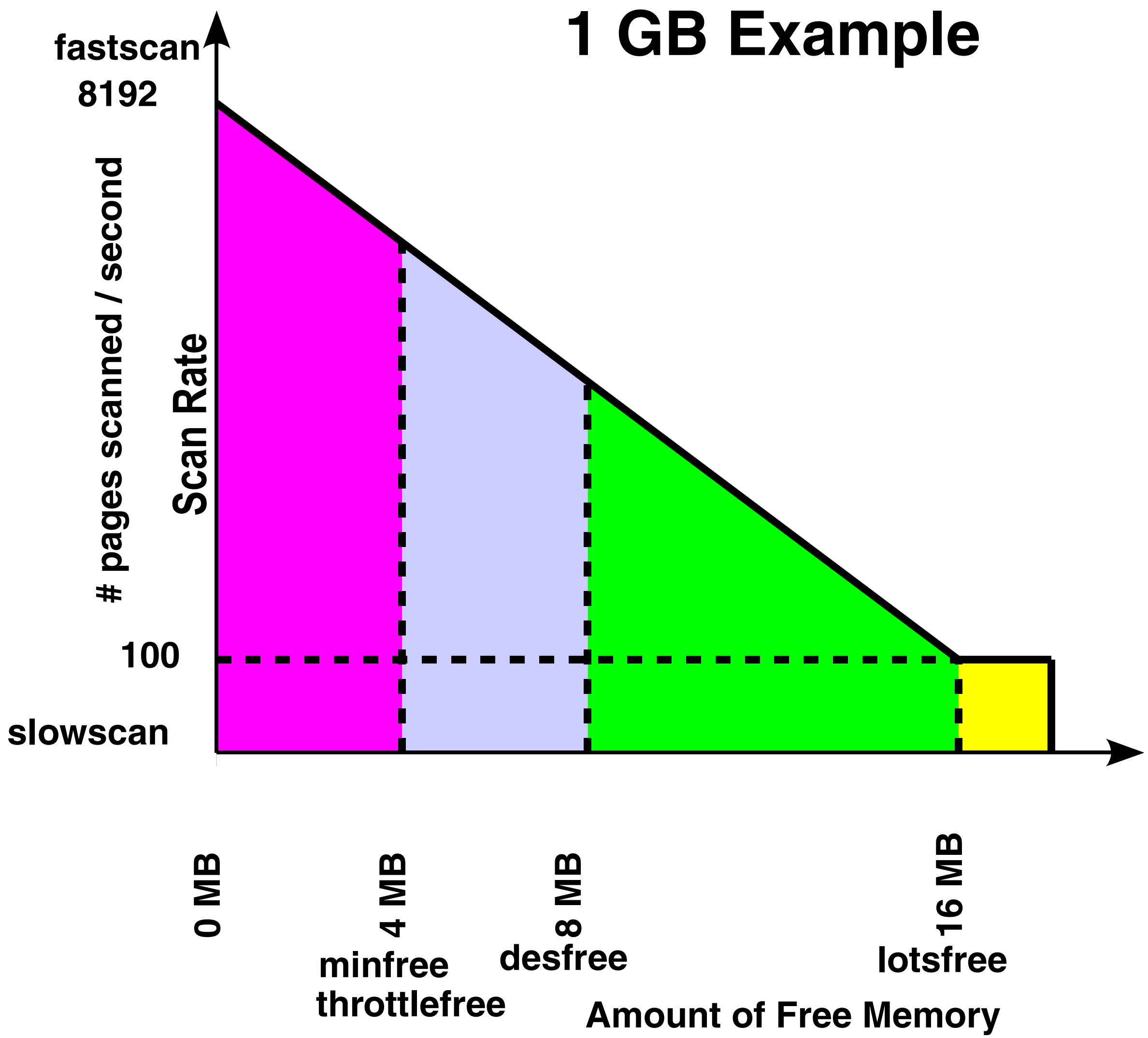
- Free memory is lower than (lotsfree)
- Starts scanning @ slowscan (pages/sec)
- Scanner Runs:
  - > four times / second when memory is short
  - > Awoken by page allocator if very low
- Limits:
  - > Max # of pages /sec. swap device can handle
  - > How much CPU should be used for scanning

$$\text{scanrate} = \left(\frac{\text{lotsfree} - \text{freemem}}{\text{lotsfree}} \times \text{fastscan}\right) + \left(\text{slowscan} \times \frac{\text{freemem}}{\text{lotsfree}}\right)$$

Scanning Parameters

Parameter	Description	Min	Default (Solaris 8)
lotsfree	starts stealing anonymous memory pages	512K	1/64 th of memory
desfree	scanner is started at 100 times/second	minfree	½ of lotsfee
minfree	start scanning every time a new page is created		½ of desfree
throttlefree	page_create routine makes the caller wait until free pages are available		minfree
fastscan	scan rate (pages per second) when free memory = minfree	slowscan	minimum of 64MB/s or ½ memory size
slowscan	scan rate (pages per second) when free memory = lotsfree		100
maxpgio	max number of pages per second that the swap device can handle	~60	60 or 90 pages per spindle
hand-spreadpages	number of pages between the front hand (clearing) and back hand (checking)	1	fastscan
min_percent_cpu	CPU usage when free memory is at lotsfree	4% (~1 clock tick)	of a single CPU

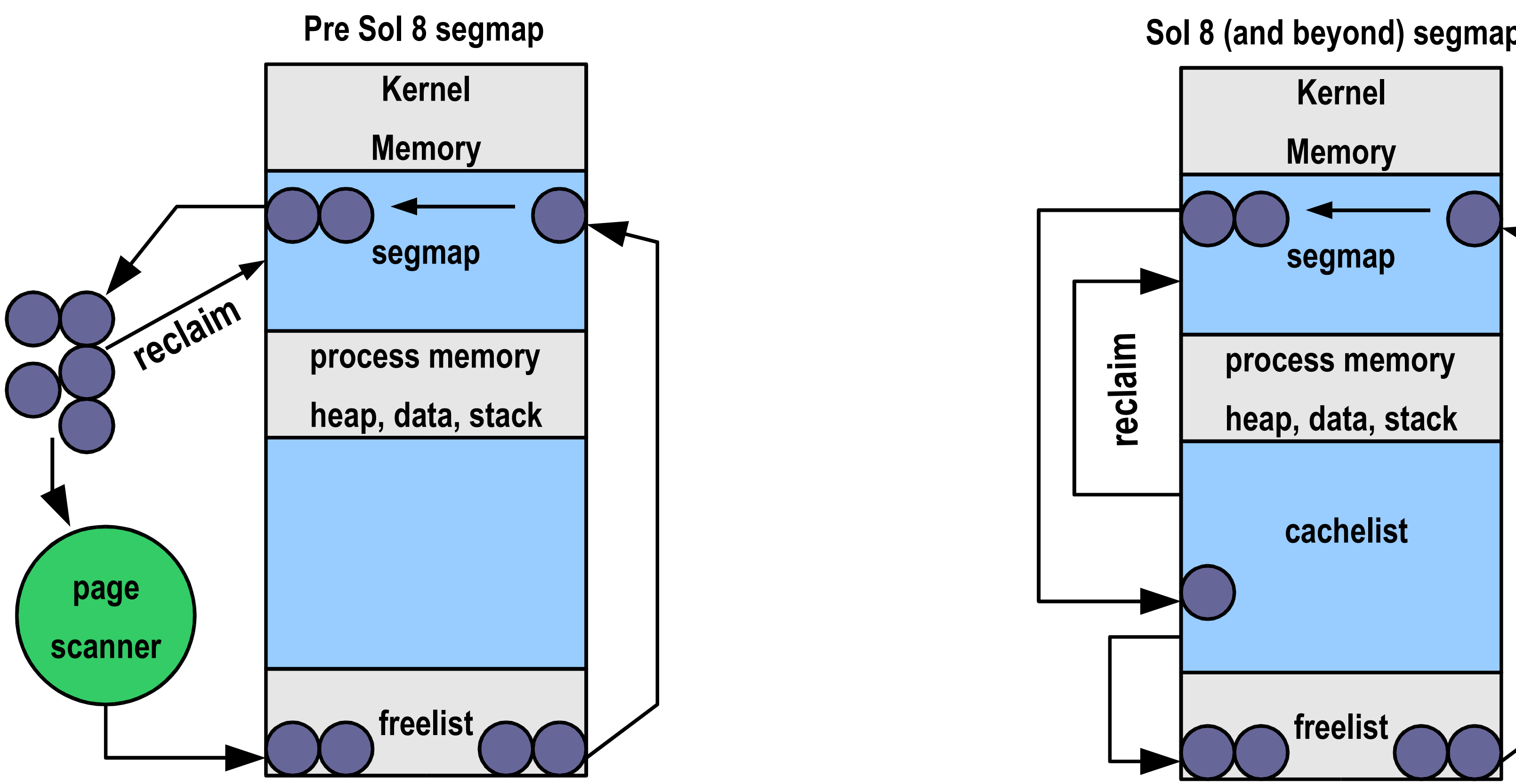
Scan Rate


1 GB Example
fastscan
8192
pages scanned / second
Scan Rate
100
slowscan
0 MB
4 MB
8 MB
16 MB
minfree
throttlefree
desfree
lotsfree
Amount of Free Memory

The Solaris Cache

- Page list is broken into two:
  - Cache List: pages with a valid vnode/offset
  - Free List: pages has no vnode/offset
- Unmapped pages where just released
- Non-dirty pages, not mapped, should be on the "free list"
- Places pages on the "tail" cache/free list
- Free memory = cache + free

The Solaris Cache



The Solaris Cache

- Now `vmstat` reports a useful `free`
- Throw away your old `/etc/system` pager configuration parameters
  - `lotsfree, desfree, minfree`
  - `fastscan, slowscan`
  - `priority_paging, cachefree`

Solaris 8/9 - VM Changes

- Observability
  - Free memory now contains file system cache
    - Higher free memory
    - vmstat 'free' column is meaningful
  - Easier visibility for memory shortages
    - Scan rates != 0 - Memory shortage
- Correct Defaults
  - No tuning required – delete all /etc/system VM parameters!

Memory Summary

Physical Memory:

```
# prtconf
System Configuration:  Sun Microsystems  sun4u
Memory size: 512 Megabytes
```

Kernel Memory:

```
# sar -k 1 1
SunOS ian 5.8 Generic_108528-03 sun4u    08/28/01
13:04:58 sml_mem   alloc  fail  lg_mem   alloc  fail  ovsz_alloc  fail
13:04:59 10059904 7392775     0 133349376 92888024     0    10346496     0
```

Free Memory:

```
# vmstat 3 3
 procs     memory            page            disk          faults      cpu
 r b w   swap  free  re  mf pi po fr de sr f0 s0 s1 s6   in   sy   cs us sy id
 0 0 0 478680 204528  0   2  0  0  0  0  0  0  0  1  0  209 1886  724 35  5 61
 0 0 0 415184 123400  0   2  0  0  0  0  0  0  0  0  0  238  825  451  2  1 98
 0 0 0 415200 123416  0   0  0  0  0  0  0  0  0  3  0  219  788  427  1  1 98
```

Solaris 9 & 10 Memory Summary

```
# mdb -k
Loading modules: [ unix krtld genunix ufs_log ip usba s1394 nfs random
ptm ipc logindmux cpc ]
> ::memstat
Page Summary                Pages                MB  %Tot
------------     ----------------  ----------------  ----
Kernel                      10145                79    4%
Anon                        21311               166    9%
Exec and libs               15531               121    6%
Page cache                  69613               543   28%
Free (cachelist)           119633               934   48%
Free (freelist)             11242                87    5%

Total                      247475              1933
```

vmstat

r = run queue length
b = processes blocked waiting for I/O
w = idle processes that have been swapped at some time
swap = free and unreserved swap in KBytes
free = free memory measured in pages
re = kilobytes reclaimed from cache/free list
mf = minor faults - the page was in memory but was not mapped
pi = kilobytes paged-in from the file system or swap device
po = kilobytes paged-out to the file system or swap device
fr = kilobytes that have been destroyed or freed
de = kilobytes freed after writes
sr = pages scanned / second
s0-s3 = disk I/Os per second for disk 0-3
in = interrupts / second
sy = system calls / second
cs = context switches / second
us = user cpu time
sy = kernel cpu time
id = idle + wait cpu time

```
# vmstat 5 5
 procs     memory            page                  disk          faults          cpu
 r b w   swap    free    re  mf  pi po  fr  de  sr  f0 s0  s1  s2   in     sy     cs    us sy id
 ...
 0 0 0 46580232 337472 18 194 30  0   0   0   0   0   0   0   0  5862  81260 28143  19  7 74
 0 0 0 45311368 336280 32 249 48  0   0   0   0   0   0   0   0  6047  93562 29039  21 10 69
 0 0 0 46579816 337048 12 216 60  0   0   0   0   0  10   0   7  5742 100944 27032  20  7 73
 0 0 0 46580128 337176  3 111  3  0   0   0   0   0   0   0   0  5569  93338 26204  21  6 73
```

vmstat -p

swap = free and unreserved swap in KBytes

free = free memory measured in pages

re = kilobytes reclaimed from cache/free list

mf = minor faults - the page was in memory but was not mapped

fr = kilobytes that have been destroyed or freed

de = kilobytes freed after writes

sr = kilobytes scanned / second

executable pages: kilobytes in - out - freed

anonymous pages: kilobytes in - out – freed

file system pages:

kilobytes in - out - freed

```
# vmstat -p 5 5
     memory           page            executable       anonymous      filesystem
   swap    free  re   mf   fr  de  sr  epi  epo  epf  api  apo  apf  fpi  fpo  fpf
 46715224 891296 24   350  0   0   0    0    0    0    4    0    0   27    0    0
 46304792 897312 151  761  25  0   0   17    0    0    1    0    0  280   25   25
 45886168 899808 118  339  1   0   0    3    0    0    1    0    0  641    1    1
 46723376 899440 29   197  0   0   0    0    0    0   40    0    0   60    0    0
```

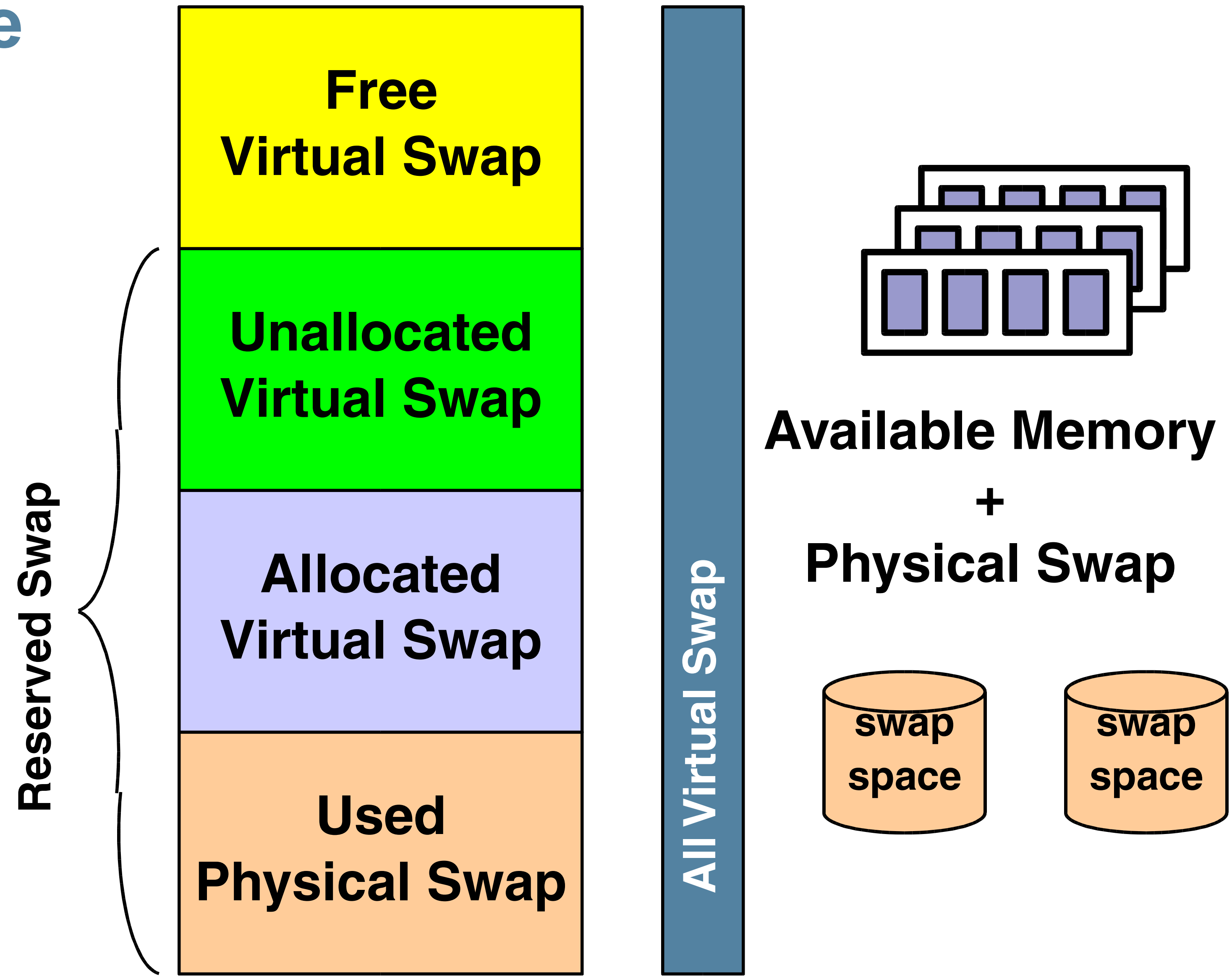
Swapping

- Scheduler/Dispatcher:
  - Dramatically affects process performance
  - Used when demand paging is not enough
- Soft swapping:
  - Avg. freemem below desfree for 30 sec.
  - Look for inactive processes, at least **`maxslp`**
- Hard swapping:
  - Run queue >= 2 (waiting for CPU)
  - Avg. freemem below desfree for 30 sec.
  - Excessive paging, **`(pageout + pagein ) > maxpgio`**
  - Aggressive; unload kernel mods & free cache

Swap space states

- Reserved:
  - > Virtual space is reserved for the segment
  - > Represents the virtual size being created
- Allocated:
  - > Virtual space is allocated when the first physical page is assigned
  - > A swapfs vnode / offset are assigned
- Swapped out:
  - > When a shortage occurs
  - > Page is swapped out by the scanner, migrated to swap storage

Swap Space


Free
Virtual Swap
Unallocated
Virtual Swap
Allocated
Virtual Swap
Used
Physical Swap
Reserved Swap
All Virtual Swap
Available Memory
+
Physical Swap
swap
space
swap
space

Swap Usage

- Virtual Swap:
  - reserved: unallocated + allocated
  - available = bytes
- `# swap -s`
- `total: 175224k bytes unallocated + 24464k allocated = 199688k reserved, 416336k available`
- Physical Swap:
  - space available for physical page-outs
  - free = blocks (512 bytes)
- `# swap -l`
- `swapfile             dev  swaplo blocks   free`
- `/dev/dsk/c0t1d0s1   32,9      16 524864 524864`
- Ensure both are non-zero
  - swap -s "available"
  - swap -l "free"

A Quick Guide to Analyzing Memory

- Quick Memory Health Check
  - Check free memory and scanning with vmstat
  - Check memory usage with ::memstat in mdb
- Paging Activity
  - Use vmstat -p to check if there are anonymous page-ins
- Attribution
  - Use DTrace to see which processes/files are causing paging
- Time based analysis
  - Use DTrace to estimate the impact of paging on application performance
- Process Memory Usage
  - Use pmap to inspect process memory usage and sharing
- MMU/Page Size Performance
  - Use trapstat to observe time spent in TLB misses

Memory Kstats – via kstat(1m)

```
sol8# kstat -n system_pages
module: unix                              instance: 0
name:   system_pages                      class:    pages
        availrmem                         343567
        crtime                            0
        desfree                           4001
        desscan                           25
        econtig                           4278190080
        fastscan                          256068
        freemem                           248309
        kernelbase                        3556769792
        lotsfree                          8002
        minfree                           2000
        nalloc                            11957763
        nalloc_calls                      9981
        nfree                             11856636
        nfree_calls                       6689
        nscan                             0
        pagesfree                         248309
        pageslocked                       168569
        pagestotal                        512136
        physmem                           522272
        pp_kernel                         64102
        slowscan                          100
        snaptime                          6573953.83957897
```

Memory Kstats – via kstat Perl API

```
%{$now} = %{$kstats->{0}{system_pages}};
print "$now->{pagesfree}\n";

sol8# wget http://www.solarisinternals.com/si/downloads/prtmem.pl
sol8# prtmem.pl 10
prtmem started on 04/01/2005 15:46:13 on devnull, sample interval 5
seconds
                     Total      Kernel        Delta         Free       Delta
15:46:18              2040         250            0          972         -12
15:46:23              2040         250            0          968          -3
15:46:28              2040         250            0          968           0
15:46:33              2040         250            0          970           1
```

Checking Paging Activity

- Good Paging
  - > Plenty of memory free
  - > Only file system page-in/page-outs (vmstat: fpi, fpo > 0)

```
%sol8# vmstat -p 3
     memory           page              executable      anonymous      filesystem
   swap  free  re  mf  fr  de  sr  epi  epo  epf  api  apo  apf  fpi  fpo  fpf
 1512488 837792 160 20 12   0   0    0    0    0    0    0    0   12   12   12
 1715812 985116 7  82   0   0   0    0    0    0    0    0    0   45    0    0
 1715784 983984 0   2   0   0   0    0    0    0    0    0    0   53    0    0
 1715780 987644 0   0   0   0   0    0    0    0    0    0    0   33    0    0
```

Checking Paging Activity

- Bad Paging
  - Non zero Scan rate (vmstat: sr >0)
  - Low free memory (vmstat: free < 1/16th physical)
  - Anonymous page-in/page-outs (vmstat: api, apo > 0)

```
sol8# vmstat -p 3
     memory           page          executable      anonymous      filesystem
   swap  free  re  mf  fr  de  sr  epi  epo  epf  api  apo  apf  fpi  fpo  fpf
 2276000 1589424 2128 19969 1 0 0    0    0    0    0    0    0    0    1    1
 1087652 388768 12 129675 13879 0 85590 0 0   12    0 3238 3238   10 9391 10630
 608036 51464  20 8853 37303 0 65871 38    0  781   12 19934 19930 95 16548 16591
  94448  8000  17 23674 30169 0 238522 16 0  810   23 28739 28804 56  547  556
```

Using prstat to estimate paging slow-downs

- Microstates show breakdown of elapsed time
  - > prstat -m
  - > USR through LAT columns summed show 100% of wallclock execution time for target thread/process
  - > DFL shows time spent waiting in major faults in anon:

```
sol8$ prstat -mL
   PID USERNAME USR SYS TRP TFL DFL LCK SLP LAT VCX ICX SCL SIG PROCESS/LWPID
 15625 rmc      0.1 0.7 0.0 0.0  95 0.0 0.9 3.2  1K 726  88   0 filebench/2
 15652 rmc      0.1 0.7 0.0 0.0  94 0.0 1.8 3.6  1K  1K  10   0 filebench/2
 15635 rmc      0.1 0.7 0.0 0.0  96 0.0 0.5 3.2  1K  1K   8   0 filebench/2
 15626 rmc      0.1 0.6 0.0 0.0  95 0.0 1.4 2.6  1K 813  10   0 filebench/2
 15712 rmc      0.1 0.5 0.0 0.0  47 0.0  49 3.8  1K 831 104   0 filebench/2
 15628 rmc      0.1 0.5 0.0 0.0  96 0.0 0.0 3.1  1K 735   4   0 filebench/2
 15725 rmc      0.0 0.4 0.0 0.0  92 0.0 1.7 5.7 996 736   8   0 filebench/2
 15719 rmc      0.0 0.4 0.0 0.0  40  40  17 2.9  1K 708 107   0 filebench/2
 15614 rmc      0.0 0.3 0.0 0.0  92 0.0 4.7 2.4 874 576  40   0 filebench/2
```

Using DTrace for memory Analysis

- The "vminfo" provider has probes at the all the places memory statistics are gathered.
- Everything visible via vmstat -p and kstat are defined as probes
  - arg0: the value by which the statistic is to be incremented. For most probes, this argument is always 1, but for some it may take other values; these probes are noted in Table 5-4.
  - arg1: a pointer to the current value of the statistic to be incremented. This value is a 64Đbit quantity that is incremented by the value in arg0. Dereferencing this pointer allows consumers to determine the current count of the statistic corresponding to the probe.

Using DTrace for Memory Analysis

- For example, if you should see the following paging activity with vmstat, indicating page-in from the swap device, you could drill down to investigate.

```
sol8# vmstat -p 3
     memory           page          executable      anonymous      filesystem
   swap  free  re  mf  fr  de  sr  epi  epo  epf  api  apo  apf  fpi  fpo  fpf
 1512488 837792 160 20 12   0   0    0    0    0 8102    0    0   12   12   12
 1715812 985116 7  82   0   0   0    0    0    0 7501    0    0   45    0    0
 1715784 983984 0   2   0   0   0    0    0    0 1231    0    0   53    0    0
 1715780 987644 0   0   0   0   0    0    0    0 2451    0    0   33    0    0

sol10$ dtrace -n anonpgin '{@[execname] = count()}'
dtrace: description anonpgin matched 1 probe
  svc.startd                                                       1
  sshd                                                             2
  ssh                                                              3
  dtrace                                                           6
  vmstat                                                          28
  filebench                                                      913
```

Using DTrace to estimate paging slow-downs

- DTrace has probes for paging
- By measuring elapsed time at the paging probes, we can see who's waiting for paging:

```
sol10$ ./whospaging.d

Who's waiting for pagein (milliseconds):
  wnck-applet                                                    21
  gnome-terminal                                                 75

Who's on cpu (milliseconds):
  wnck-applet                                                    13
  gnome-terminal                                                 14
  metacity                                                       23
  Xorg                                                           90
  sched                                                        3794
```

Using DTrace to estimate paging slow-downs

- DTrace has probes for paging
- By measuring elapsed time at the paging probes, we can see who's waiting for paging:

```
sol10$ ./pagingtime.d 22599

  <on cpu>                                                         913
  <paging wait>                                                 230704
```

To a Terabyte and Beyond: Utilizing and Tuning Large Memory

Who said this?

“640k ought to be enough for everyone”

Who said this?

“640k ought to be enough for everyone”

> Bill Gates, 1981

Large Memory

- Large Memory in Perspective
- 64-bit Solaris
- 64-bit Hardware
- Solaris enhancements for Large Memory
- Large Memory Databases
- Configuring Solaris for Large Memory
- Using larger page sizes

Application Dataset Growth

- Commercial applications
  - > RDBMS caching for SQL & Disk blocks using up to 500GB
  - > Supply Chain models now reaching 200GB
- Virtual Machines
  - > 1 Address space for all objects, JVM today is 100GB+
- Scientific/Simulation/Modelling
  - > Oil/Gas, Finite element, Bioinformatics models 500GB+
  - > Medium size mechanical models larger than 4GB
- Desktops: Low end 512MB today, 4GB in 2006?

Large memory in perspective

- 640k:
  - > 19 bits of address space is enough?
  - > 3 years later we ran out of bits...
- 32-bit systems will last for ever?
  - > 4 Gigabytes
  - > 10 years after introduction we ran out of bits again

64-bits – enough for everyone?

- 64-bits – finally we won't run out...
- 16 Exabytes!
- That's 16,384 Peta-bytes
- However: 1PB is feasible today
- That's only 14 bits x 1Petabyte
- If we grow by 1 bit per year
  - > We'll run out of bits again in 2020...

Solaris

Full 64-bit support (Solaris 7 and beyond)

64-bit Solaris

- LP64 Data Model
- 32-bit or 64-bit kernel, with 32-bit & 64-bit application support
  - > 64-bit on SPARC
  - > Solaris 10 64-bit on AMD64 (Opteron, Athlon)
- Comprehensive 32-bit application compatibility

Why 64-bit for large memory?

- Extends the existing programming model to large memory
- Existing POSIX APIs extend to large data types (e.g. file offsets. file handle limits eliminated)
- Simple transition of existing source to 64-bits

Developer Perspective

- Virtually unlimited address space
  - Data objects, files, large hardware devices can be mapped into virtual address space
  - 64-bit data types, parameter passing
  - Caching can be implemented in application, yielding much higher performance
- Small Overheads

Exploiting 64-bits

- Commercial: Java Virtual Machine, SAP, Microfocus Cobol, ANTS, XMS, Multigen
- RDBMS: Oracle, DB2, Sybase, Informix, Times Ten
- Mechanical/Design: PTC, Unigraphics, Mentor Graphics, Cadence, Synopsis etc...
- Supply Chain: I2, SAP, Manugistics
- HPC: PTC, ANSYS, ABAQUS, Nastran, LS-Dyna, Fluent etc...

Large Memory Hardware

- DIMMS
  - > 2GB DIMMS: 16GB/CPU
  - > 1GB DIMMS: 8GB/CPU
  - > 512MB DIMMS: 4GB/CPU
- SF6800/SF6900: 192GB Max
  - > 8GB/CPU
- F25k: 1152GB Max
  - > 16GB/CPU

Large Memory Solaris

- Solaris 7: 64-bits
- Solaris 8: 80GB
- Solaris 8 U6: 320GB
- Solaris 8 U7: 576GB
- Solaris 9: 1.1TB
- Solaris 10: 1.1TB

Large Memory Solaris (cont)

- Solaris 8
  - > New VM, large memory fs cache
- Solaris 8, 2/02
  - > Large working sets MMU perf
  - > Raise 8GB limit to 128GB
  - > Dump Performance improved
  - > Boot performance improved
- Solaris 9
  - > Generic multiple page size facility and tools
- Solaris 10
  - > Large kernel pages

Configuring Solaris

- fsflush uses too much CPU on Solaris 8
  - > Set "autoup" in /etc/system
  - > Symptom is one CPU using 100%sys
- Corrective Action
  - > Default is 30s, recommend setting larger
  - > e.g. 10x nGB of memory

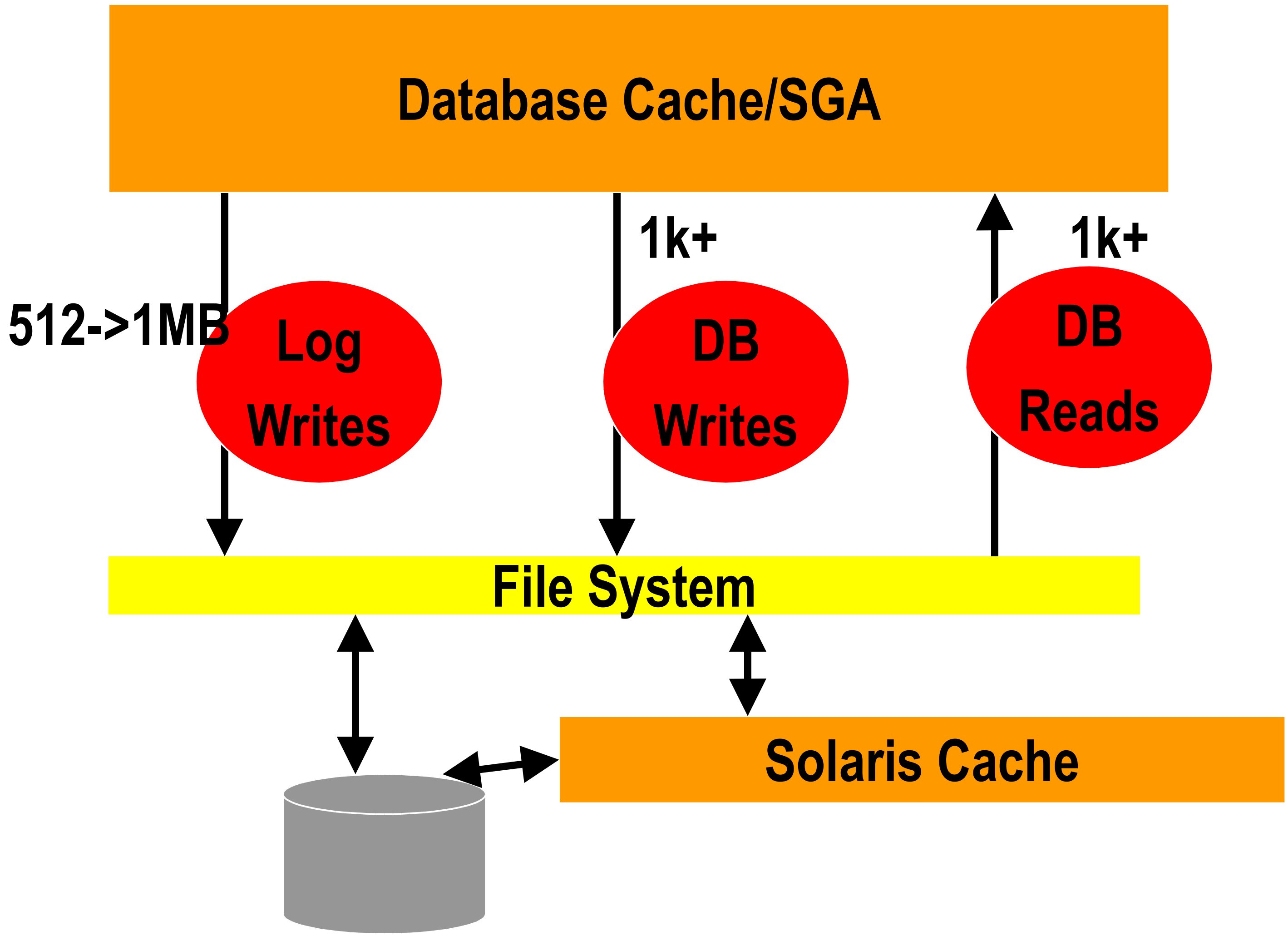
Large Dump Performance

- Configure “kernel only”
  - > Dumpadm
- Estimate dump as 20% of memory size
- Configure separate dump device
  - > Reliable dumps
  - > Asynchronous saves during boot (savecore)
- Configure a fast dump device
  - > T3 Stripe as a dump device

Databases

- Exploit memory to reduce/eliminate I/O!
- Eliminating I/O is the easiest way to tune it...
- Increase cache hit rates:
  - > 95% means 1 out 20 accesses result in I/O
  - > 99% means 1 out of 100 – 500% reduction in I/O!
- We can often fit entire RDBMS in memory
- Write-mostly I/O pattern results

Oracle File I/O



64-Bit Oracle

- Required to cache more than 3.75GB
- Available since DBMS 8.1.7
- Sun has tested up to 540GB SGA
- Recommended by Oracle and Sun
- Cache for everything except PQ
- Pay attention to cold-start times

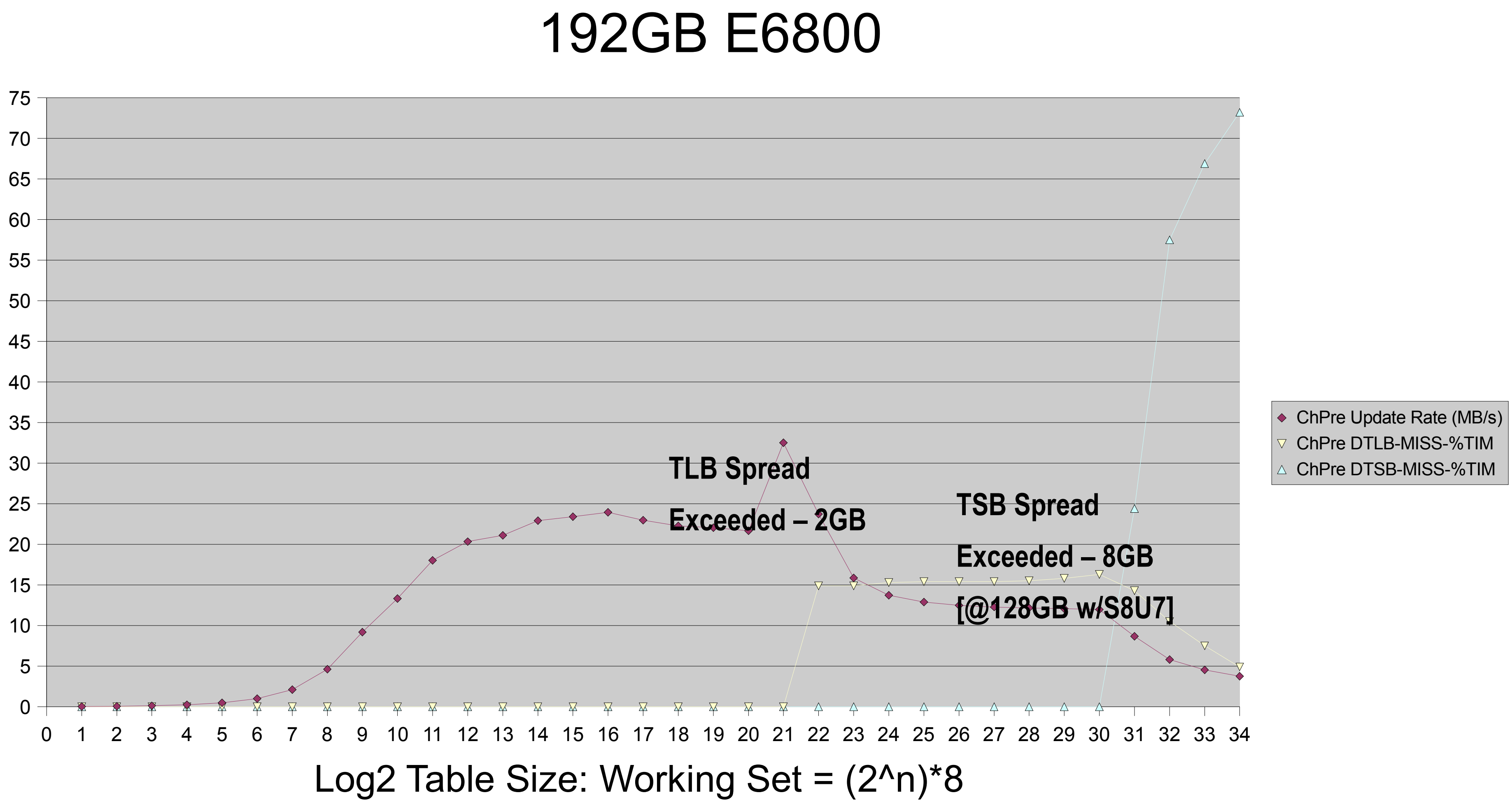
Solaris 8/9 Large Pages

- Solaris 8
  - Large (4MB) pages with ISM/DISM for shared memory
- Solaris 9/10
  - Multiple Page Size Support (MPSS)
    - Optional large pages for heap/stack
    - Programmatically via madvise()
    - Shared library for existing binaries (LD_PRELOAD)
    - Tool to observe potential gains
      - `# trapstat -t`

Do I need Large Pages?

- Is the application memory intensive?
- How much time is being wasted in MMU traps?
  - MMU traps are not visible with %usr/%sys
  - MMU traps are counted in the current context
  - e.g. User-bound process reports as %usr

TLB Performance Knees



Trapstat Introduction

```
sol9# trapstat -t 1 111
cpu m| itlb-miss %tim itsb-miss %tim | dtlb-miss %tim dtsb-miss %tim |%tim
-----+-------------------------------+-------------------------------+----
  0 u|         1  0.0         0  0.0 |   2171237 45.7         0  0.0 |45.7
  0 k|         2  0.0         0  0.0 |      3751  0.1         7  0.0 | 0.1
=====+===============================+===============================+====
 ttl |         3  0.0         0  0.0 |   2192238 46.2         7  0.0 |46.2
```

- This application *might* run almost 2x faster!

Observing MMU traps

```
sol9# trapstat -T 1 111
cpu m size| itlb-miss %tim itsb-miss %tim | dtlb-miss %tim dtsb-miss %tim |%tim
----------+-------------------------------+-------------------------------+----
  0 u   8k|        30  0.0         0  0.0 |   2170236 46.1         0  0.0 |46.1
  0 u  64k|         0  0.0         0  0.0 |         0  0.0         0  0.0 | 0.0
  0 u 512k|         0  0.0         0  0.0 |         0  0.0         0  0.0 | 0.0
  0 u   4m|         0  0.0         0  0.0 |         0  0.0         0  0.0 | 0.0
- - - - - + - - - - - - - - - - - - - - - + - - - - - - - - - - - - - - - + - -
  0 k   8k|         1  0.0         0  0.0 |      4174  0.1        10  0.0 | 0.1
  0 k  64k|         0  0.0         0  0.0 |         0  0.0         0  0.0 | 0.0
  0 k 512k|         0  0.0         0  0.0 |         0  0.0         0  0.0 | 0.0
  0 k   4m|         0  0.0         0  0.0 |         0  0.0         0  0.0 | 0.0
==========+===============================+===============================+====
      ttl |        31  0.0         0  0.0 |   2174410 46.2        10  0.0 |46.2
```

Observing MMU traps

```
sol9# trapstat -t 1 111
cpu m| itlb-miss %tim itsb-miss %tim | dtlb-miss %tim dtsb-miss %tim |%tim
-----+-------------------------------+-------------------------------+----
  0 u|         1  0.0         0  0.0 |   2171237 45.7         0  0.0 |45.7
  0 k|         2  0.0         0  0.0 |      3751  0.1         7  0.0 | 0.1
=====+===============================+===============================+====
 ttl |         3  0.0         0  0.0 |   2192238 46.2         7  0.0 |46.2
```

Available Page Sizes

SPARC

```
solaris10> isainfo
sparcv9 sparc
solaris10> pagesize -a
8192
65536
524288
4194304
solaris10>
```

AMD64

```
solaris10> isainfo
amd64 i386
solaris10> pagesize -a
4096
2097152
solaris10>
```

Setting Page Sizes

- Solution: Use the wrapper program
  - Sets page size preference
  - Doesn't persist across exec()

```
sol9# ppgsz -o heap=4M ./testprog
```

Checking Allocated Page Sizes

```
Sol9# pmap -sx `pgrep testprog`
2953:   ./testprog
 Address  Kbytes     RSS    Anon  Locked Pgsz Mode   Mapped File
00010000       8       8       -       -   8K r-x--  dev:277,83 ino:114875
00020000       8       8       8       -   8K rwx--  dev:277,83 ino:114875
00022000    3960    3960    3960       -   8K rwx--    [ heap ]
00400000  131072  131072  131072       -   4M rwx--    [ heap ]
FF280000     120     120       -       -   8K r-x--  libc.so.1
FF340000       8       8       8       -   8K rwx--  libc.so.1
FF390000       8       8       -       -   8K r-x--  libc_psr.so.1
FF3A0000       8       8       -       -   8K r-x--  libdl.so.1
FF3B0000       8       8       8       -   8K rwx--    [ anon ]
FF3C0000     152     152       -       -   8K r-x--  ld.so.1
FF3F6000       8       8       8       -   8K rwx--  ld.so.1
FFBFA000      24      24      24       -   8K rwx--    [ stack ]
-------- ------- ------- ------- -------
total Kb  135968  135944  135112       -
```

TLB traps eliminated

```
sol9# trapstat -T 1 111
cpu m size| itlb-miss %tim itsb-miss %tim | dtlb-miss %tim dtsb-miss %tim |%tim
----------+-------------------------------+-------------------------------+----
  0 u   8k|       30  0.0         0  0.0 |        36  0.1         0  0.0 | 0.1
  0 u  64k|        0  0.0         0  0.0 |         0  0.0         0  0.0 | 0.0
  0 u 512k|        0  0.0         0  0.0 |         0  0.0         0  0.0 | 0.0
  0 u   4m|        0  0.0         0  0.0 |         0  0.0         0  0.0 | 0.0
- - - - - + - - - - - - - - - - - - - - - + - - - - - - - - - - - - - - - + - -
  0 k   8k|        1  0.0         0  0.0 |      4174  0.1        10  0.0 | 0.1
  0 k  64k|        0  0.0         0  0.0 |         0  0.0         0  0.0 | 0.0
  0 k 512k|        0  0.0         0  0.0 |         0  0.0         0  0.0 | 0.0
  0 k   4m|        0  0.0         0  0.0 |         0  0.0         0  0.0 | 0.0
==========+===============================+===============================+====
      ttl |       31  0.0         0  0.0 |      4200  0.2        10  0.0 | 0.2
```

Solution: Use the preload lib.

```
sol9# LD_PRELOAD=$LD_PRELOAD:mpss.so.1
sol9# export LD_PRELOAD=$LD_PRELOAD:mpss.so.1
sol9# export MPSSHEAP=4M
sol9# ./testprog
MPSSHEAP=size
MPSSSTACK=size
MPSSHEAP and MPSSSTACK specify the preferred page
sizes for the heap and stack, respectively. The speci-
fied page size(s) are applied to all created
processes.
MPSSCFGFILE=config-file
config-file is a text file which contains one or more
mpss configuration entries of the form:
exec-name:heap-size:stack-size
```

What about Solaris 8?

```
sol8# cpustat -c pic0=Cycle_cnt,pic1=DTLB_miss 1
time cpu event pic0 pic1
1.006 0 tick 663839993 3540016
2.006 0 tick 651943834 3514443
3.006 0 tick 630482518 3398061
4.006 0 tick 634483028 3418046
5.006 0 tick 651910256 3511458
6.006 0 tick 651432039 3510201
7.006 0 tick 651512695 3512047
8.006 0 tick 613888365 3309406
9.006 0 tick 650806115 3510292
```

Tips for UltraSPARC revs

- UltraSPARC II
  - Up to four page sizes can be used
  - 8k,64k,512k,4M
- UltraSPARC III 750Mhz
  - Optimized for 8k
  - Only one large page size
  - 7 TLB entries for large pages
  - Pick from 64k, 512k, 4M
- UltraSPARC III+ (900Mhz+)
  - Only one large page size
  - 512 TLB entries for large pages
- UltraSPARC IV

Solaris 8/9 Large Pages

- Solaris 8
  - Large (4MB) pages with ISM/DISM for shared memory
- Solaris 9 & 10
  - Multiple Page Size Support (MPSS)
    - Optional large pages for heap/stack
    - Programmatically via madvise()
    - Shared library for existing binaries (LD_PRELOAD)
    - Tool to observe potential gains
      - `# trapstat -t`

Address Spaces: A Deeper Dive

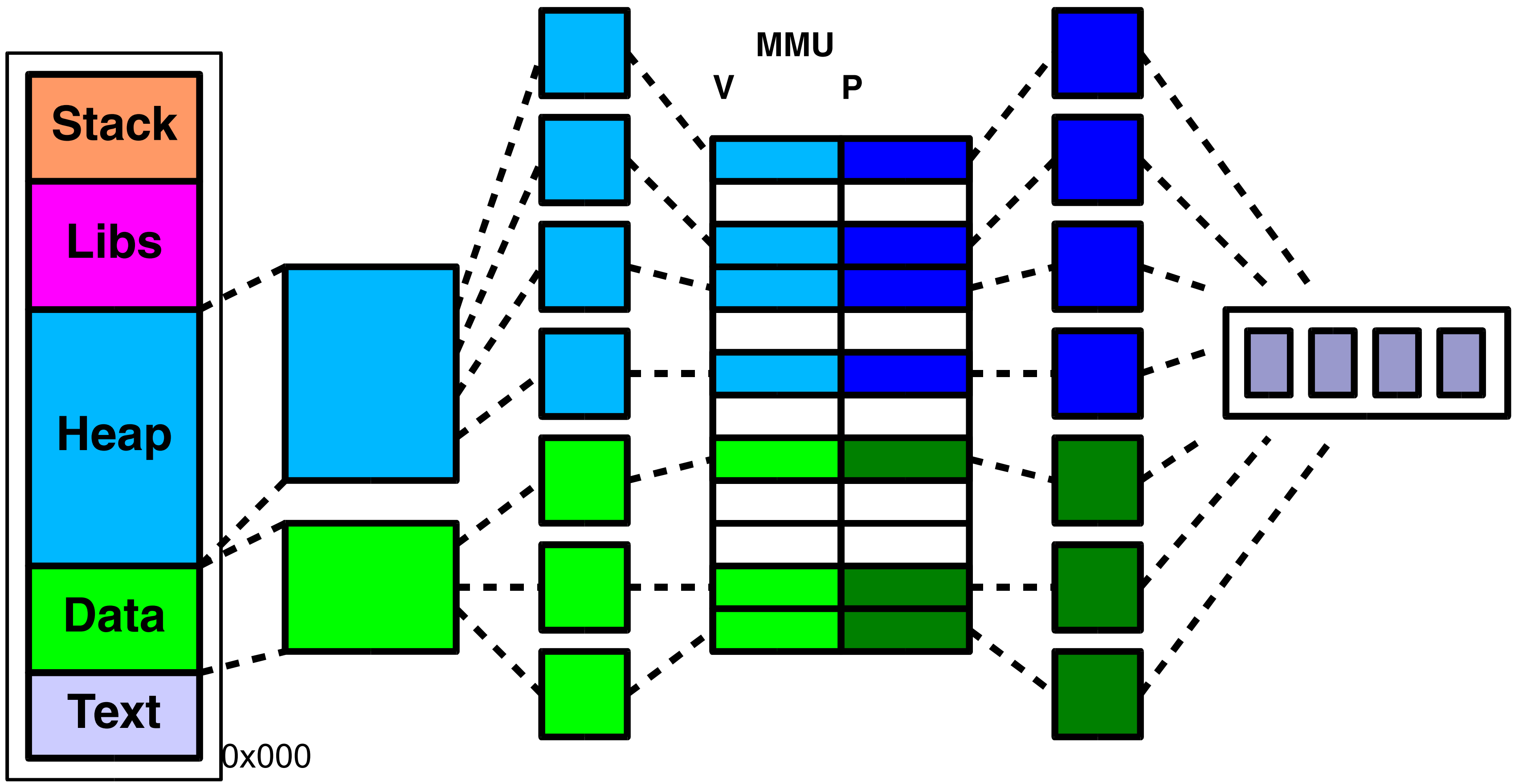
Example Program

```
#include <sys/types.h>
const char * const_str = "My const string";
char * global_str = "My global string";
int    global_int = 42;
int
main(int argc, char * argv[])
{
        int local_int = 123;
        char * s;
        int i;
        char command[1024];


        global_int = 5;
        s = (char *)malloc(14000);
        s[0] = 'a';
        s[100] = 'b';
        s[8192] = 'c';

}
```

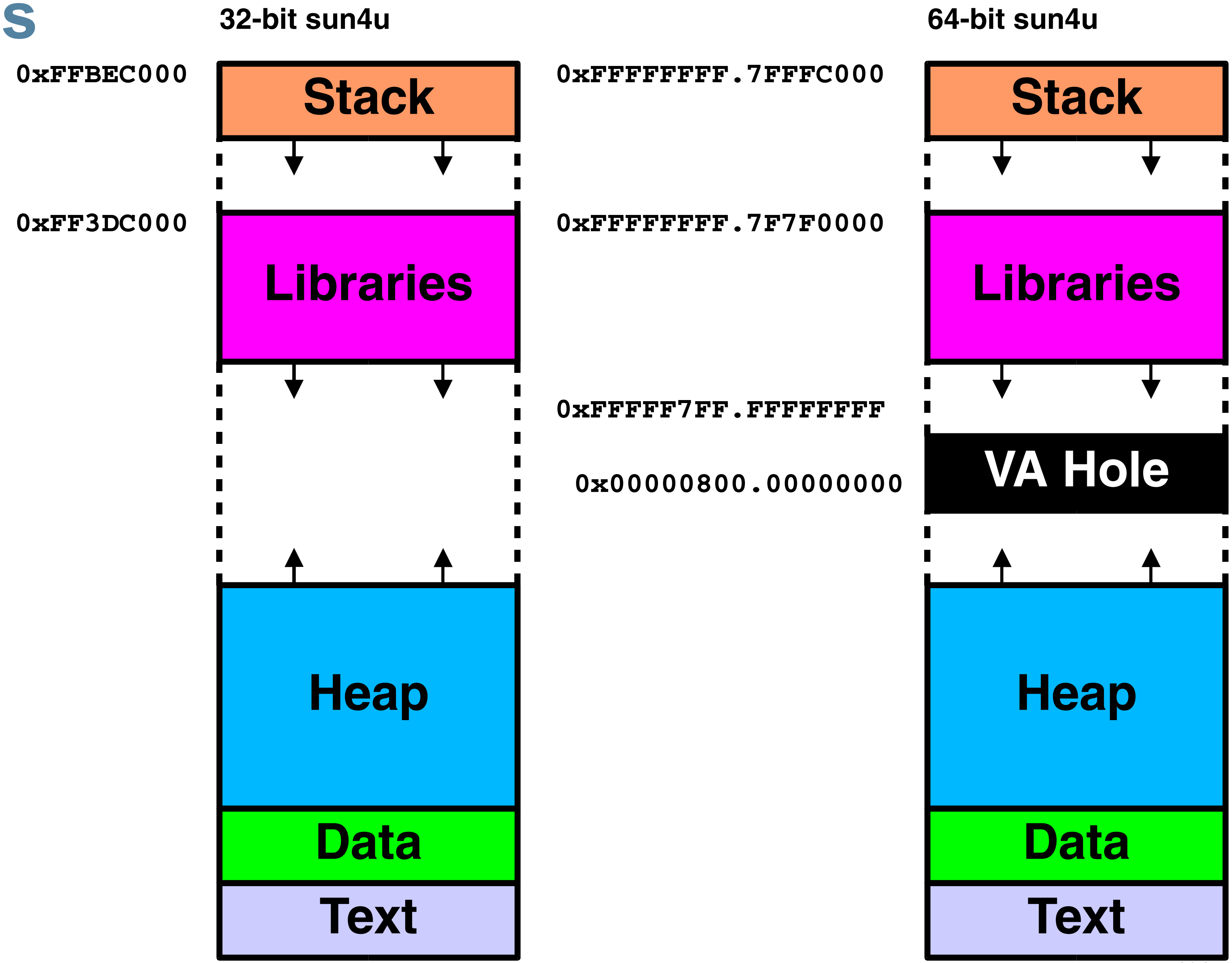
Virtual to Physical

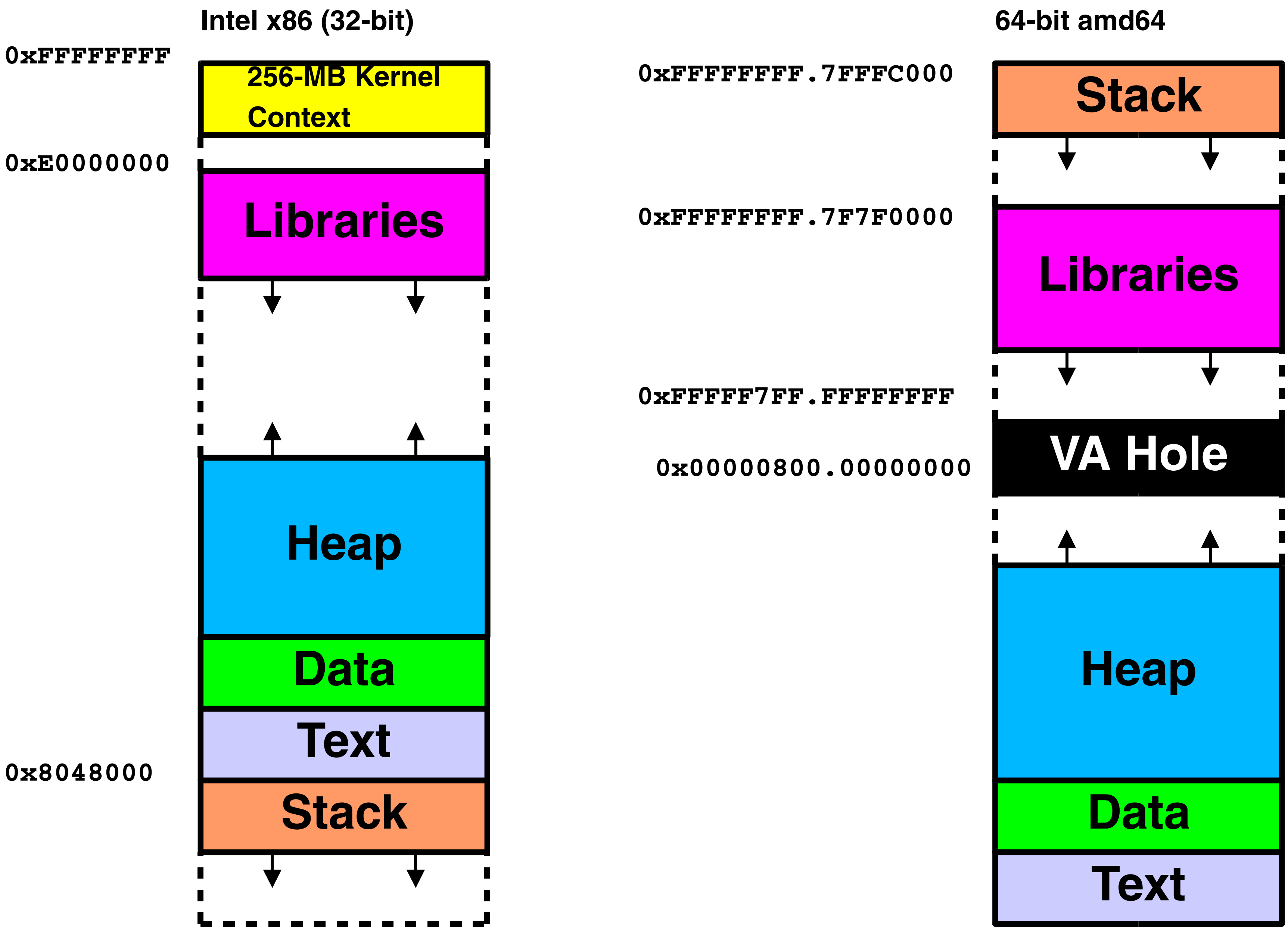


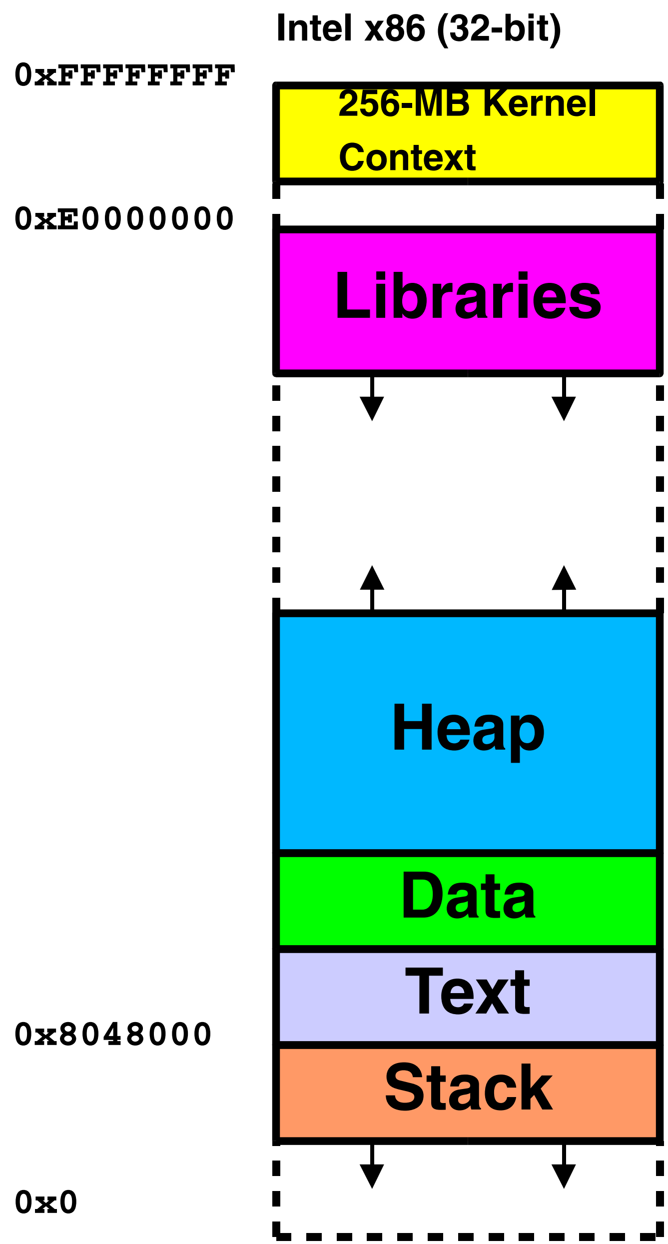
Address Space

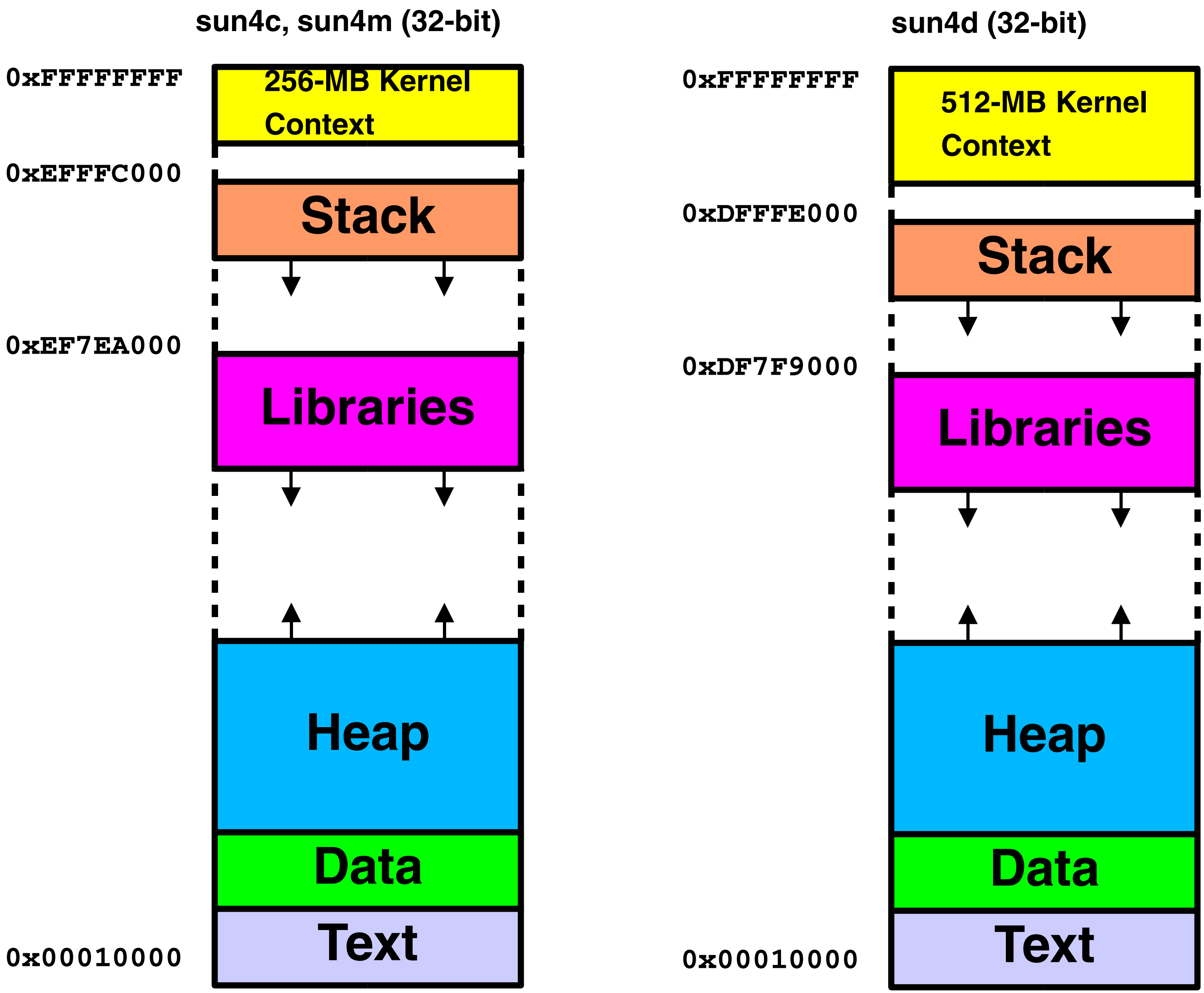
- Process Address Space
  - Process Text and Data
  - Stack (anon memory) and Libraries
  - Heap (anon memory)
- Kernel Address Space
  - Kernel Text and Data
  - Kernel Map Space (data structs, caches)
  - 32-bit Kernel map (64-bit Kernels only)
  - Trap table
  - Critical virtual memory data structures
  - Mapping File System Cache (segmap)

Address Space




Intel x86 (32-bit)
0xFFFFFFFF
256-MB Kernel Context
0xE0000000
Libraries
Heap
Data
Text
0x8048000
Stack
64-bit amd64
0xFFFFFFFF.7FFFC000
Stack
0xFFFFFFFF.7F7F0000
Libraries
0xFFFFF7FF.FFFFFFFF
VA Hole
0x00000800.00000000
Heap
Data
Text


Intel x86 (32-bit)
0xFFFFFFFF
256-MB Kernel
Context
0xE0000000
Libraries
Heap
Data
Text
0x8048000
Stack
0x0


sun4c, sun4m (32-bit)
0xFFFFFFFF
256-MB Kernel Context
0xEFFFC000
Stack
0xEF7EA000
Libraries
Heap
Data
Text
0x00010000
sun4d (32-bit)
0xFFFFFFFF
512-MB Kernel Context
0xDFFFE000
Stack
0xDF7F9000
Libraries
Heap
Data
Text
0x00010000

pmap -x

```
Sol8# /usr/proc/bin/pmap -x $$
18084:   csh
 Address    Kbytes Resident Shared Private Permissions        Mapped File
00010000      144      144    136       8 read/exec           csh
00044000       16       16      -      16 read/write/exec     csh
00048000      120      104      -     104 read/write/exec       [ heap ]
FF200000      672      624    600      24 read/exec           libc.so.1
FF2B8000       24       24      -      24 read/write/exec     libc.so.1
FF2BE000        8        8      -       8 read/write/exec     libc.so.1
FF300000       16       16      8       8 read/exec           libc_psr.so.1
FF320000        8        8      -       8 read/exec           libmapmalloc.so.1
FF332000        8        8      -       8 read/write/exec     libmapmalloc.so.1
FF340000        8        8      -       8 read/write/exec       [ anon ]
FF350000      168      112     88      24 read/exec           libcurses.so.1
FF38A000       32       32      -      32 read/write/exec     libcurses.so.1
FF392000        8        8      -       8 read/write/exec     libcurses.so.1
FF3A0000        8        8      -       8 read/exec           libdl.so.1
FF3B0000      136      136    128       8 read/exec           ld.so.1
FF3E2000        8        8      -       8 read/write/exec     ld.so.1
FFBE6000       40       40      -      40 read/write/exec       [ stack ]
--------   ------   ------ ------  ------
total Kb     1424     1304    960     344
```

Process Heap Sizes

Solaris Version	Max Heap Size	Notes
Solaris 2.5	2 GBytes	
Solaris 2.5.1	2 GBytes	
Solaris 2.5.1 w/ patch 103640-08 or greater	3.75 GBytes	Need to reboot to increase limit above 2 GB with ulimit
Solaris 2.5.1 w/ patch 103640-23 or greater	3.75 GBytes	Do not need to be root to increase limit
Solaris 2.6	3.75 GBytes	Need to increase beyond 2GB with ulimit
Solaris 7 or 8 (32-bit mode)	3.75 / 3.90 GBytes	non-sun4u / sun4u
Solaris 7 or 8 (64-bit mode)	16 TBytes (Ultra)	Virtually unlimited
Solaris 9 (32-bit)	3.75 / 3.90 GBytes	non-sun4u / sun4u
Solaris 9 (64-bit)	16 TBytes (Ultra)	Virtually unlimited
Solaris 10 SPARC 32bit app	3.90GB	sun4u
Solaris 10 SPARC 64bit app	16 TBytes (Ultra)	64-bit only on SPARC
Solaris 10 32-bit x86	<TBD>	
Solaris 10 64-bit x64	16 TBytes (Ultra)	AMD64

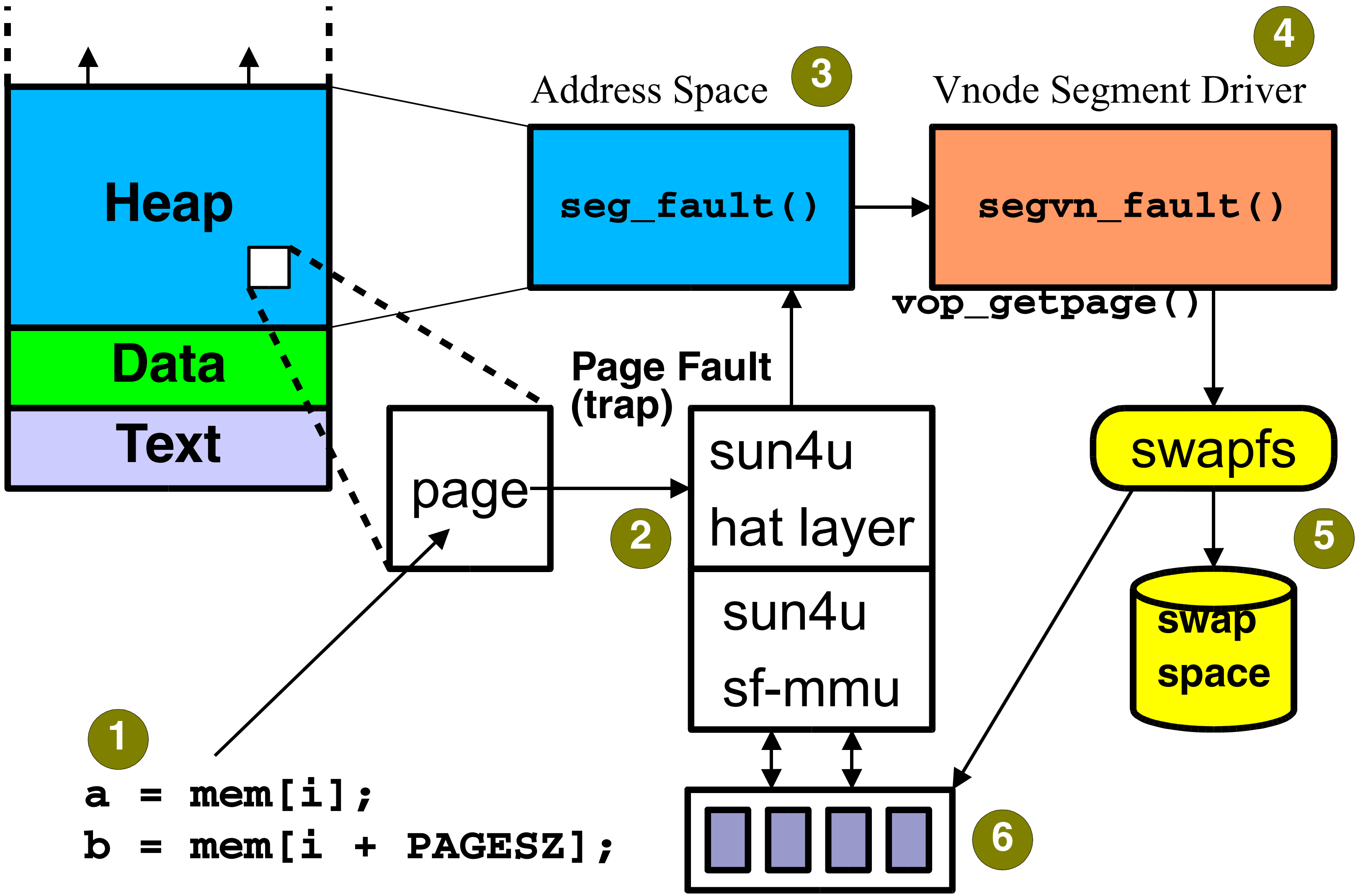
Address Space Management

- Duplication; `fork() -> as_dup()`
- Destruction; `exit()`
- Creation of new segments
- Removal of segments
- Page protection (read, write, executable)
- Page Fault routing
- Page Locking
- Watchpoints

Page Faults

- MMU-generated exception:
- Major Page Fault:
  - Failed access to VM location, in a segment
  - Page does not exist in physical memory
  - New page is created or copied from swap
  - If addr not in a valid segment (SIG-SEGV)
- Minor Page Fault:
  - Failed access to VM location, in a segment
  - Page is in memory, but no MMU translation
- Page Protection Fault:
  - An access that violates segment protection

Page Fault Example:




```
a = mem[i];
b = mem[i + PAGESZ];
```

vmstat -p

swap = free and unreserved swap in KBytes

free = free memory measured in pages

re = kilobytes reclaimed from cache/free list

mf = minor faults - the page was in memory but was not mapped

fr = kilobytes that have been destroyed or freed

de = kilobytes freed after writes

sr = kilobytes scanned / second

executable pages: kilobytes in - out - freed

anonymous pages: kilobytes in - out – freed

file system pages:

kilobytes in - out - freed

```
# vmstat -p 5 5
     memory           page          executable      anonymous      filesystem
   swap    free  re  mf  fr  de  sr  epi  epo  epf  api  apo  apf  fpi  fpo  fpf
 46715224 891296 24  350 0   0   0    0    0    0    4    0    0   27    0    0
 46304792 897312 151 761 25  0   0   17    0    0    1    0    0  280   25   25
 45886168 899808 118 339 1   0   0    3    0    0    1    0    0  641    1    1
 46723376 899440 29  197 0   0   0    0    0    0   40    0    0   60    0    0
```

Examining paging with dtrace VM Provider

- The dtrace VM provider provides a probe for each VM statistic
- We can observe all VM statistics via kstat:

```
$ kstat -n vm
module: cpu                               instance: 0
name:   vm                                class:    misc
        anonfree                          0
        anonpgin                          0
        anonpgout                         0
        as_fault                          3180528
        cow_fault                         37280
        crtime                            463.343064
        dfree                             0
        execfree                          0
        execpgin                          442
        execpgout                         0
        fsfree                            0
        fspgin                            2103
        fspgout                           0
        hat_fault                         0
        kernel_asflt                      0
        maj_fault                         912
```

Examining paging with dtrace

- Suppose one were to see the following output from vmstat(1M):

```
kthr memory page disk faults cpu
r b w swap    free   re   mf   pi po fr de sr  cd s0s1 s2  in   sy   cs us sy id
0 1 0 1341844 836720 26   311 1644  0  0  0  0 216 0  0  0 797  817  697 9  10 81
0 1 0 1341344 835300 238 934 1576  0  0  0  0 194 0  0  0 750 2795  791 7  14 79
0 1 0 1340764 833668 24   165 1149  0  0  0  0 133 0  0  0 637  813  547 5  4  91
0 1 0 1340420 833024 24   394 1002  0  0  0  0 130 0  0  0 621 2284  653 14 7  79
0 1 0 1340068 831520 14   202  380  0  0  0  0  59 0  0  0 482 5688 1434 25 7  68
```

- The pi column in the above output denotes the number of pages paged in. The vminfo provider makes it easy to learn more about the source of these page-ins:

```
dtrace -n pgin {@[execname] = count()}
dtrace: description ÕpginÕ matched 1 probe
^C
xterm 1
ksh 1
ls 2
lpstat 7
sh 17
soffice 39
javaldx 103
soffice.bin 3065
```

Examining paging with dtrace

- From the above, we can see that a process associated with the StarOffice Office Suite, soffice.bin, is reponsible for most of the page-ins.
- To get a better picture of soffice.bin in terms of VM behavior, we may wish to enable all vminfo probes.
- In the following example, we run dtrace(1M) while launching StarOffice:

```
dtrace -P vminfo/execname == "soffice.bin"/{@[probename] = count()}
dtrace: description vminfo matched 42 probes
^C
pgout 16
anonfree 16
anonpgout 16
pgpgout 16
dfree 16
execpgin 80
prot_fault 85
maj_fault 88
pgin 90
pgpgin 90
cow_fault 859
zfod 1619
pgfrec 8811
pgrec 8827
as_fault 9495
```

Examining paging with dtrace

- To further drill down on some of the VM behavior of StarOffice during startup, we could write the following D script:

```
vminfo:::maj_fault, vminfo:::zfod, vminfo:::as_fault
/execname == "soffice.bin" && start == 0/
{
  /*
   * This is the first time that a vminfo probe has been hit; record
   * our initial timestamp.
   */
  start = timestamp;
}
vminfo:::maj_fault, vminfo:::zfod,vminfo:::as_fault
/execname == "soffice.bin"/
{
  /*
   * Aggregate on the probename, and lquantize() the number of seconds
   * since our initial timestamp. (There are 1,000,000,000 nanoseconds
   * in a second.) We assume that the script will be terminated before
   * 60 seconds elapses.
   */
  @[probename] = lquantize((timestamp - start) / 1000000000, 0, 60);
}
```

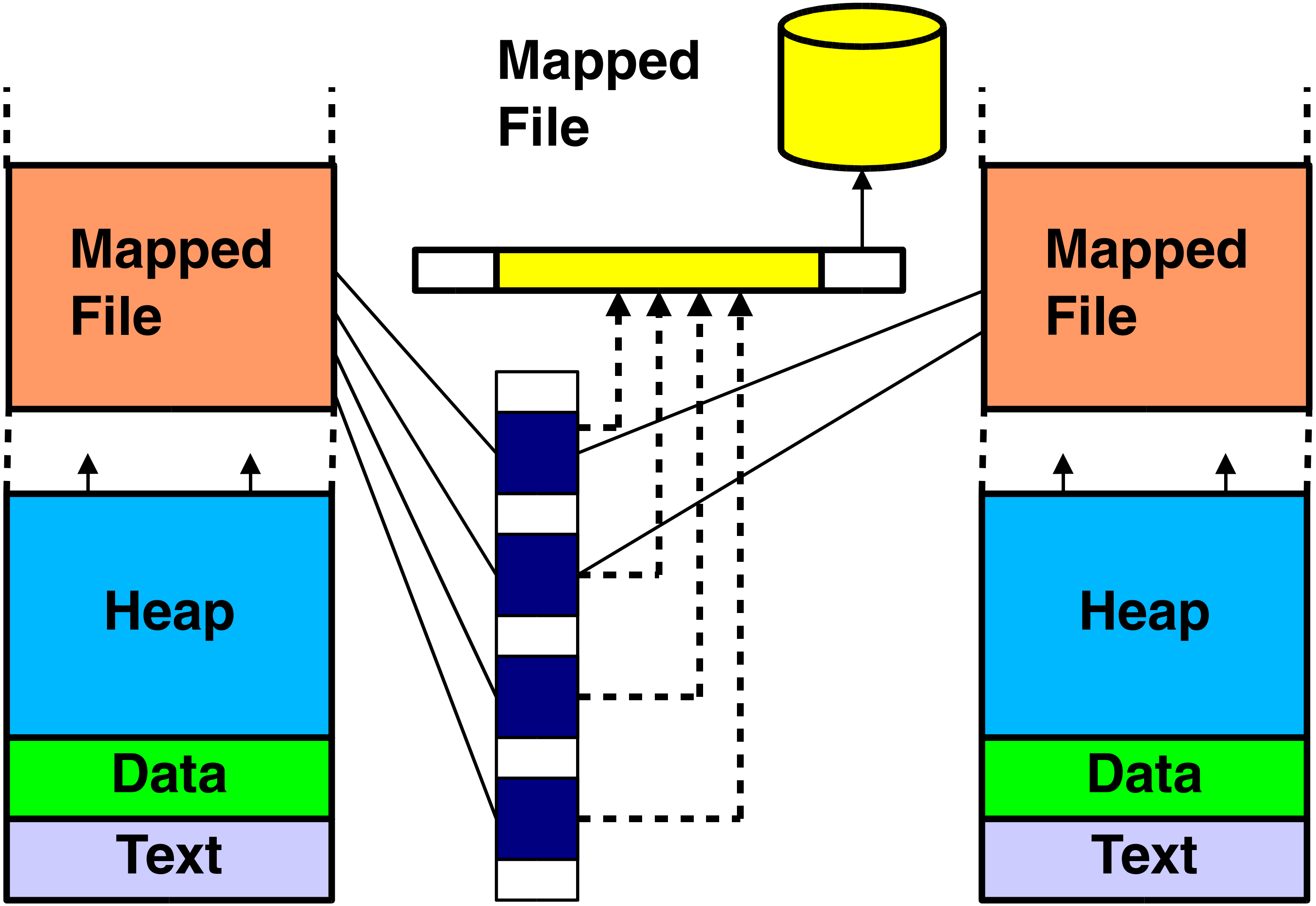
Examining paging with dtrace

```
# dtrace -s ./soffice.d
dtrace: script Õ./soffice.dÕ matched 10 probes
^C
maj_fault
value ------------- Distribution ------------- count
7    |                                           0
8    |  @@@@@@@@@                                88
9    |  @@@@@@@@@@@@@@@@@@@@                     194
10   |  @                                        18
11   |                                           0
12   |                                           0
13   |                                           2
14   |                                           0
15   |                                           1
16   |  @@@@@@@@                                 82
17   |                                           0
18   |                                           0
19   |                                           2
20   |                                           0
```

Examining paging with dtrace

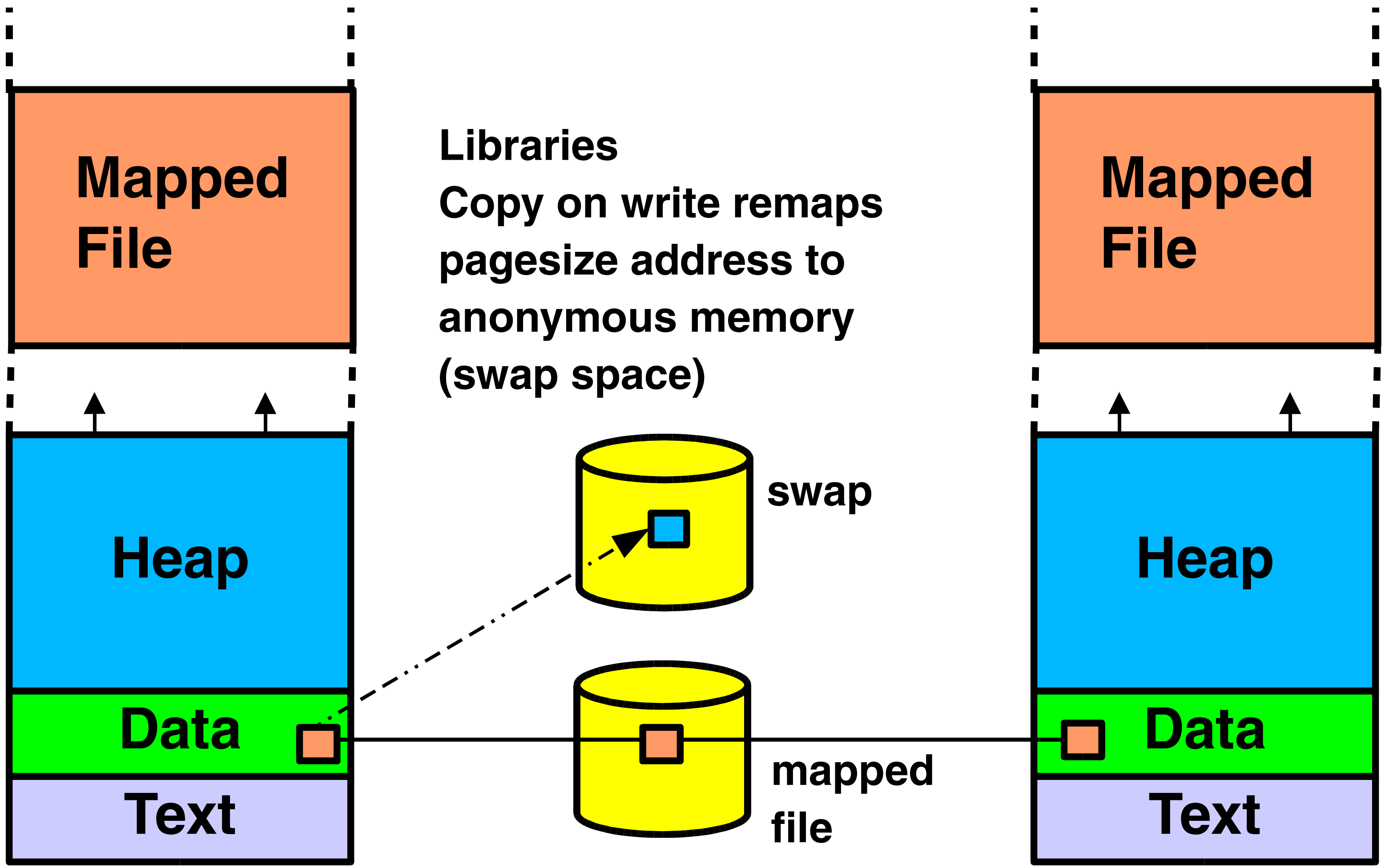
```
Zfod
value ------------- Distribution ------------- count
< 0  |                                          0
0    |@@@@@@@                                   525
1    |@@@@@@@@                                  605
2    |@@                                        208
3    |@@@                                       280
4    |                                          4
5    |                                          0
6    |                                          0
7    |                                          0
8    |                                          44
9    |@@                                        161
10   |                                          2
11   |                                          0
12   |                                          0
13   |                                          4
14   |                                          0
15   |                                          29
16   |@@@@@@@@@@@@@@                            1048
17   |                                          24
18   |                                          0
19   |                                          0
20   |                                          1
21   |                                          0
22   |                                          3
23   |                                          0
```

Shared Mapped File



Copy-on-write

Libraries
Copy on write remaps pagesize address to anonymous memory (swap space)



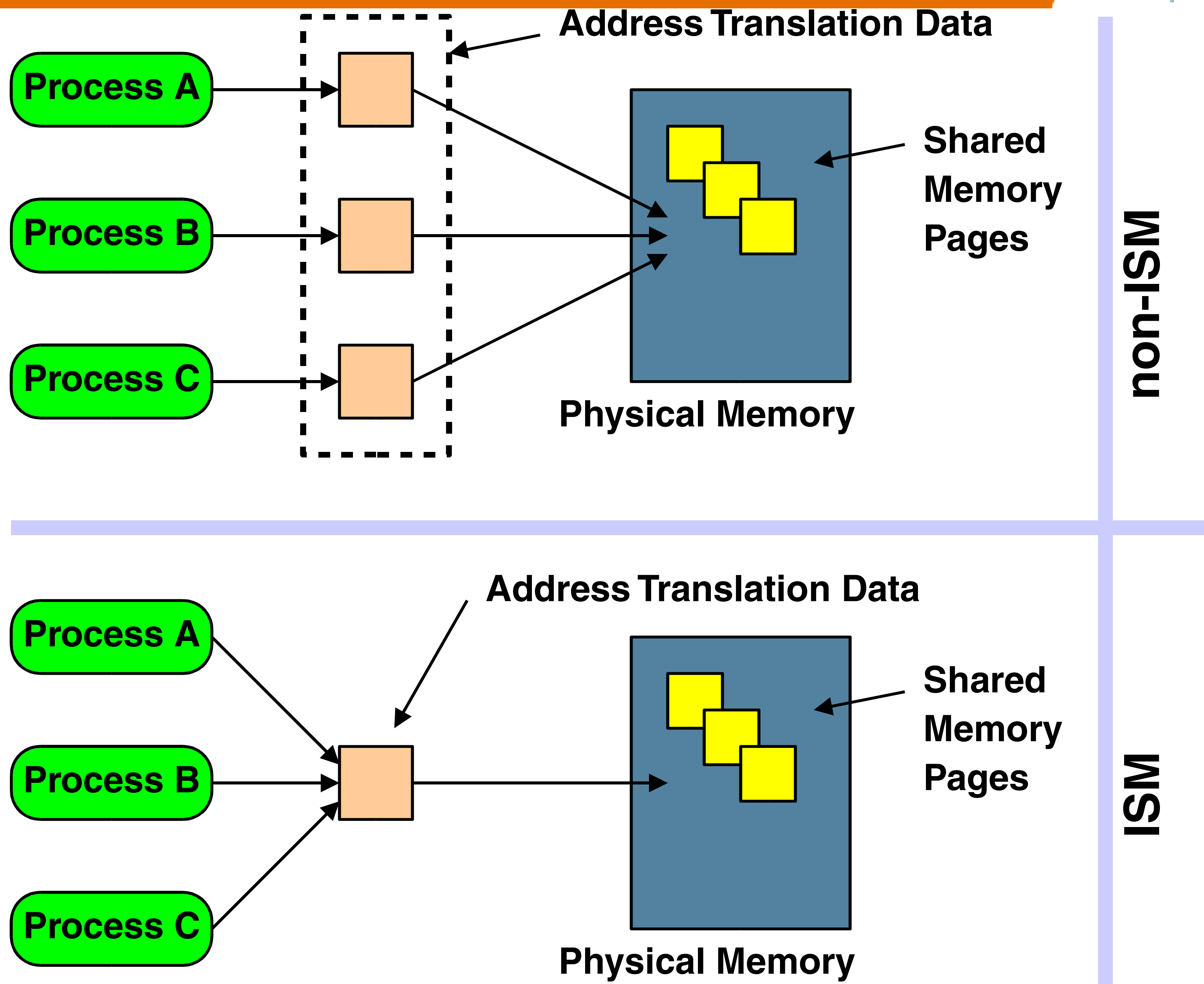
Anonymous Memory

- Pages not "directly" backed by a vnode
- Heap, Stack and Copy-On-Write pages
- Pages are reserved when "requested"
- Pages allocated when "touched"
- Anon layer:
  - > creates slot array for pages
  - > Slots point to Anon structs
- Swapfs layer:
  - > Pseudo file system for anon layer
  - > Provides the backing store

Intimate Shared Memory

- System V shared memory (ipc) option
- Shared Memory optimization:
  - > Additionally share low-level kernel data
  - > Reduce redundant mapping info (V-to-P)
- Shared Memory is locked, never paged
  - > No swap space is allocated
- Use **`SHM_SHARE_MMU`** flag in **`shmat()`**

ISM



Address Translation Data
Process A
Process B
Process C
Shared Memory Pages
Physical Memory
non-ISM
Address Translation Data
Process A
Process B
Process C
Shared Memory Pages
Physical Memory
ISM

Session 3
Processes, Threads, Scheduling Classes & The Dispatcher

Process/Threads Glossary

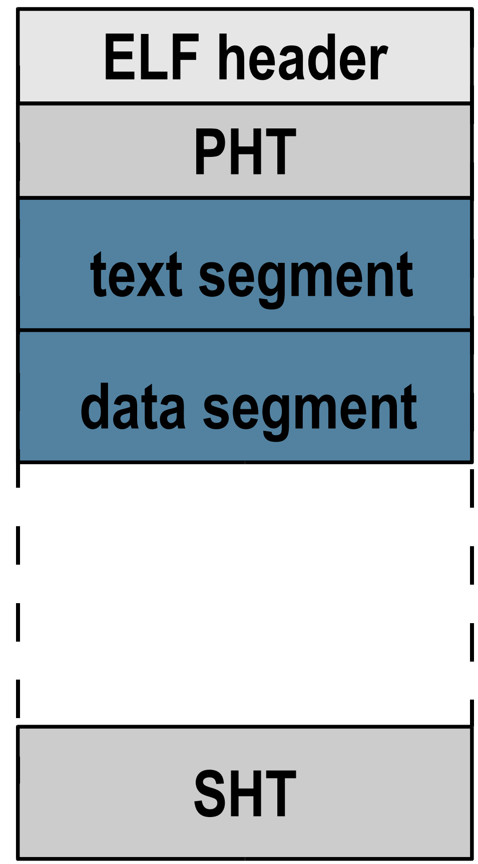
Process	The executable form of a program. An Operating System abstraction that encapulates the execution context of a program
Thread	An executable entity
User Thread	A thread within the address space of a process
Kernel Thread	A thread in the address space of the kernel
Lightweight Process	LWP – An execution context for a kernel thread
Dispatcher	The kernel subsystem that manages queues of runnable kernel threads
Scheduling Class	Kernel classes that define the scheduling parameters (e.g. priorities) and algorithms used to multiplex threads onto processors
Dispatch Queues	Per-processor sets of queues of runnable threads (run queues)
Sleep Queues	Queues of sleeping threads
Turnstiles	A special implementation of sleep queues that provide priority inheritance.

Executable Files

- Processes originate as executable programs that are exec'd
- Executable & Linking Format (ELF)
  - Standard executable binary file Application Binary Interface (ABI) format
  - Two standards components
    - Platform independent
    - Platform dependent (SPARC, x86)
  - Defines both the on-disk image format, and the in-memory image
  - ELF files components defined by
    - ELF header
    - Program Header Table (PHT)
    - Section Header Table (SHT)

Executable & Linking Format (ELF)

- ELF header
  - > Roadmap to the file
- PHT
  - > Array of Elf_Phdr structures, each defines a segment for the loader (exec)
- SHT
  - > Array of Elf_Shdr structures, each defines a section for the linker (ld)



ELF Files

- ELF on-disk object created by the link-editor at the tail-end of the compilation process (although we still call it an a.out by default...)
- ELF objects can be statically linked or dynamically linked
  - > Compiler "-B static" flag, default is dynamic
  - > Statically linked objects have all references resolved and bound in the binary (libc.a)
  - > Dynamically linked objects rely on the run-time linker, ld.so.1, to resolve references to shared objects at run time (libc.so.1)
  - > Static linking is discouraged, and not possible for 64-bit binaries

Examing ELF Files

- Use `elfdump`(1) to decompose ELF files

```
borntorun> elfdump -e /bin/ls

ELF Header
  ei_magic:   { 0x7f, E, L, F }
  ei_class:   ELFCLASS32          ei_data:      ELFDATA2MSB
  e_machine:  EM_SPARC            e_version:    EV_CURRENT
  e_type:     ET_EXEC
  e_flags:                     0
  e_entry:               0x10f00  e_ehsize:     52  e_shstrndx:   26
  e_shoff:                0x4654  e_shentsize:  40  e_shnum:      27
  e_phoff:                  0x34  e_phentsize:  32  e_phnum:       6
borntorun>
```

Examining ELF Files

- `elfdump` -c dumps section headers

```
borntorun> elfdump -c /bin/ls
Section Header[11]:  sh_name: .text
    sh_addr:       0x10f00          sh_flags:   [ SHF_ALLOC  SHF_EXECINSTR ]
    sh_size:       0x2ec4           sh_type:    [ SHT_PROGBITS ]
    sh_offset:     0xf00            sh_entsize: 0
    sh_link:       0                sh_info:    0
    sh_addralign:  0x8

Section Header[17]:  sh_name: .got
    sh_addr:       0x24000          sh_flags:   [ SHF_WRITE  SHF_ALLOC ]
    sh_size:       0x4              sh_type:    [ SHT_PROGBITS ]
    sh_offset:     0x4000           sh_entsize: 0x4
    sh_link:       0                sh_info:    0
    sh_addralign:  0x2000

Section Header[18]:  sh_name: .plt
    sh_addr:       0x24004          sh_flags:   [ SHF_WRITE  SHF_ALLOC  SHF_EXECINSTR ]
    sh_size:       0x28c            sh_type:    [ SHT_PROGBITS ]
    sh_offset:     0x4004           sh_entsize: 0xc
    sh_link:       0                sh_info:    0
    sh_addralign:  0x4

Section Header[22]:  sh_name: .data
    sh_addr:       0x24380          sh_flags:   [ SHF_WRITE  SHF_ALLOC ]
    sh_size:       0x154            sh_type:    [ SHT_PROGBITS ]
    sh_offset:     0x4380           sh_entsize: 0
    sh_link:       0                sh_info:    0
    sh_addralign:  0x8
```

Examing ELF Linker Dependencies

- Use `ldd`(1) to invoke the runtime linker (ld.so) on a binary file, and `pldd`(1) on a running process

```
borntorun> ldd netstat
        libdhcpagent.so.1 =>   /usr/lib/libdhcpagent.so.1
        libcmd.so.1 =>     /usr/lib/libcmd.so.1
        libsocket.so.1 => /usr/lib/libsocket.so.1
        libnsl.so.1 =>     /usr/lib/libnsl.so.1
        libkstat.so.1 =>  /usr/lib/libkstat.so.1
        libc.so.1 =>  /usr/lib/libc.so.1
        libdl.so.1 =>      /usr/lib/libdl.so.1
        libmp.so.2 =>      /usr/lib/libmp.so.2
        /usr/platform/SUNW,Ultra-60/lib/libc_psr.so.1
```

```
borntorun> pldd $$
495: ksh
/usr/lib/libsocket.so.1
/usr/lib/libnsl.so.1
/usr/lib/libc.so.1
/usr/lib/libdl.so.1
/usr/lib/libmp.so.2
/usr/platform/sun4u/lib/libc_psr.so.1
/usr/lib/locale/en_US.ISO8859-1/en_US.ISO8859-1.so.2
borntorun>
```

Runtime Linker Debug

```
solaris> LD_DEBUG=help date
00000:
...
00000: args       display input argument processing (ld only)
00000: audit      display runtime link-audit processing (ld.so.1 only)
00000: basic      provide basic trace information/warnings
00000: bindings   display symbol binding; detail flag shows absolute:relative
00000:              addresses (ld.so.1 only)
00000: cap        display hardware/software capability processing
00000: detail     provide more information in conjunction with other options
00000: demangle   display C++ symbol names in their demangled form
00000: entry      display entrance criteria descriptors (ld only)
00000: files      display input file processing (files and libraries)
00000: got        display GOT symbol information (ld only)
00000: help       display this help message
00000: libs       display library search paths; detail flag shows actual
00000:              library lookup (-l) processing
00000: long       display long object names without truncation
00000: map        display map file processing (ld only)
00000: move       display move section processing
00000: reloc      display relocation processing
00000: sections   display input section processing (ld only)
00000: segments   display available output segments and address/offset
00000:              processing; detail flag shows associated sections (ld only)
00000: statistics display processing statistics (ld only)
00000: strtab     display information about string table compression; detail
00000:              shows layout of string tables (ld only)
. . . .
```

Runtime Linker Debug - Libs

```
solaris> LD_DEBUG=libs /opt/filebench/bin/filebench
13686:
13686: hardware capabilities - 0x2b  [ VIS  V8PLUS  DIV32  MUL32 ]
...
13686: find object=libc.so.1; searching
13686:  search path=/lib  (default)
13686:  search path=/usr/lib  (default)
13686:  trying path=/lib/libc.so.1
13686: 1: calling .init (from sorted order): /lib/libc.so.1
13686: 1: calling .init (done): /lib/libc.so.1
13686: 1: transferring control: /opt/filebench/bin/filebench
13686: 1:  trying path=/platform/SUNW,Ultra-Enterprise/lib/libc_psr.so.1
...
13686: find object=libm.so.2; searching
13686:  search path=/usr/lib/lwp/sparcv9  (RPATH from file /
opt/filebench/bin/sparcv9/filebench)
13686:  trying path=/usr/lib/lwp/sparcv9/libm.so.2
13686:  search path=/lib/64  (default)
13686:  search path=/usr/lib/64  (default)
13686:  trying path=/lib/64/libm.so.2
13686:
13686: find object=libl.so.1; searching
13686:  search path=/usr/lib/lwp/sparcv9  (RPATH from file /
opt/filebench/bin/sparcv9/filebench)
13686:  trying path=/usr/lib/lwp/sparcv9/libl.so.1
13686:  search path=/lib/64  (default)
13686:  search path=/usr/lib/64  (default)
13686:  trying path=/lib/64/libl.so.1
13686:  trying path=/usr/lib/64/libl.so.1
```

Runtime Linker Debug - Bindings

```
solaris> LD_DEBUG=bindings /opt/filebench/bin/filebench
15151:
15151: hardware capabilities - 0x2b  [ VIS  V8PLUS  DIV32  MUL32 ]
15151: configuration file=/var/ld/ld.config: unable to process file
15151: binding file=/opt/filebench/bin/filebench to 0x0 (undefined weak): symbol
`__1cG__CrunMdo_exit_code6F_v_'
15151: binding file=/opt/filebench/bin/filebench to file=/lib/libc.so.1: symbol `__iob'
15151: binding file=/lib/libc.so.1 to 0x0 (undefined weak): symbol `__tnf_probe_notify'
15151: binding file=/lib/libc.so.1 to file=/opt/filebench/bin/filebench: symbol `_end'
15151: binding file=/lib/libc.so.1 to 0x0 (undefined weak): symbol `_ex_unwind'
15151: binding file=/lib/libc.so.1 to file=/lib/libc.so.1: symbol `__fnmatch_C'
15151: binding file=/lib/libc.so.1 to file=/lib/libc.so.1: symbol `__getdate_std'
...
15151: binding file=/opt/filebench/bin/sparcv9/filebench to file=/lib/64/libc.so.1: symbol
`__iob'
15151: binding file=/opt/filebench/bin/sparcv9/filebench to file=/lib/64/libc.so.1: symbol
`optarg'
15151: binding file=/lib/64/libm.so.2 to file=/opt/filebench/bin/sparcv9/filebench: symbol
`free'
15151: binding file=/lib/64/libm.so.2 to file=/lib/64/libm.so.2: symbol `__signgamf'
15151: binding file=/lib/64/libm.so.2 to file=/lib/64/libm.so.2: symbol `__signgaml'
15151: binding file=/lib/64/libm.so.2 to file=/lib/64/libm.so.2: symbol `__xpg6'
...
15151: 1: binding file=/lib/64/libc.so.1 to file=/lib/64/libc.so.1: symbol `_sigemptyset'
15151: 1: binding file=/lib/64/libc.so.1 to file=/lib/64/libc.so.1: symbol `_sigaction'
```

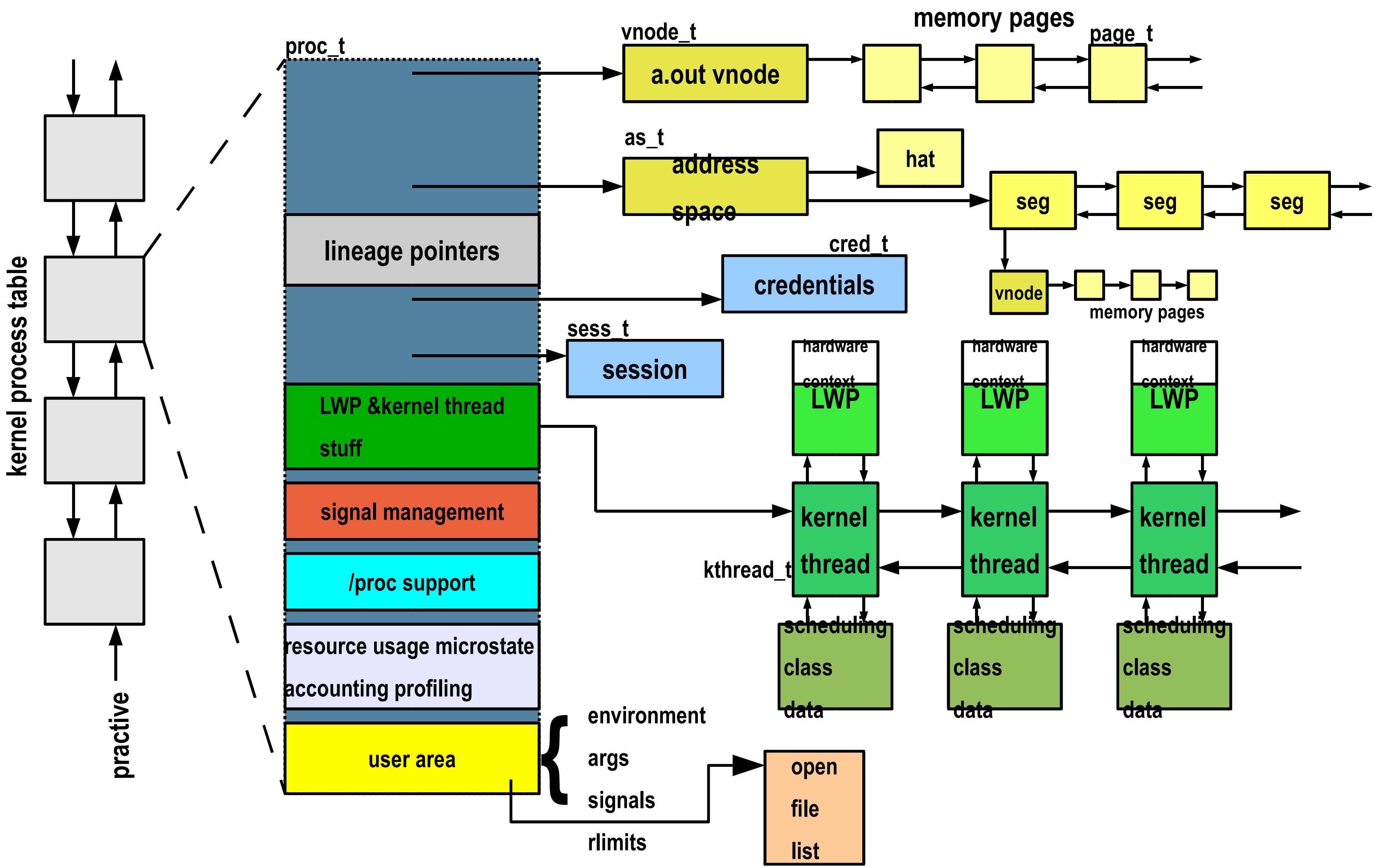
Runtime Linker – Debug

- Explore the options in *The Linker and Libraries Guide*

Solaris Process Model

- Solaris implements a multithreaded process model
  - Kernel threads are scheduled/executed
  - LWPs allow for each thread to execute system calls
  - Every kernel thread has an associated LWP
  - A non-threaded process has 1 kernel thread/LWP
  - A threaded process will have multiple kernel threads
  - All the threads in a process share all of the process context
    - Address space
    - Open files
    - Credentials
    - Signal dispositions
  - Each thread has its own stack

Solaris Process



Process Structure

```
# mdb -k
Loading modules: [ unix krtld genunix specfs dtrace ufs ip sctp usba fctl nca lofs nfs random
sppp crypto ptm logindmux cpc ]
> ::ps
S    PID   PPID   PGID    SID    UID      FLAGS             ADDR NAME
R      0      0      0      0      0 0x00000001 fffffffffbc1ce80 sched
R      3      0      0      0      0 0x00020001 ffffffff880838f8 fsflush
R      2      0      0      0      0 0x00020001 ffffffff88084520 pageout
R      1      0      0      0      0 0x42004000 ffffffff88085148 init
R  21344      1  21343  21280   2234 0x42004000 ffffffff95549938 tcpPerfServer
...
> ffffffff95549938::print proc_t
{
    p_exec = 0xffffffff9285dc40
    p_as = 0xffffffff87c776c8
    p_cred = 0xffffffff8fdeb448
    p_lwpcnt = 0x6
    p_zombcnt = 0
    p_tlist = 0xffffffff8826bc20
        .....
        u_ticks = 0x16c6f425
        u_comm = [ "tcpPerfServer" ]
        u_psargs = [ "/export/home/morgan/work/solaris_studio9/bin/tcpPerfServer 9551 9552" ]
        u_argc = 0x3
        u_argv = 0x8047380
        u_envp = 0x8047390
        u_cdir = 0xffffffff8bf3d7c0
        u_saved_rlimit = [
            {
                rlim_cur = 0xfffffffffffffffd
                rlim_max = 0xfffffffffffffffd
            }
        ......
            fi_nfiles = 0x3f
            fi_list = 0xffffffff8dc44000
            fi_rlist = 0
        }
    p_model = 0x100000
    p_rctls = 0xffffffffa7cbb4c8
    p_dtrace_probes = 0
    p_dtrace_count = 0
    p_dtrace_helpers = 0
    p_zone = zone0
```

Kernel Process Table

- Linked list of all processes (proc structures)
- kmem_cache allocator dynamically allocates space needed for new proc structures
  - > Up to v.v_proc

```
borntorun> kstat -n var
module: unix                            instance: 0
name:   var                             class:    misc
      crtime                          61.041156087
      snaptime                        113918.894449089
      v_autoup                        30
      v_buf                           100
      v_bufhwm                        20312
      [snip]
      v_maxsyspri                     99
      v_maxup                         15877
      v_maxupttl                      15877
      v_nglobpris                     110
      v_pbuf                          0
      v_proc                          15882
      v_sptmap                        0
```

```
# mdb -k
Loading modules: [ unix krtld genunix ... ptm ipc ]
> max_nprocs/D
max_nprocs:
max_nprocs:     15882
>
```

System-wide Process View - ps(1)

```
 F S      UID   PID  PPID   C PRI NI     ADDR     SZ    WCHAN    STIME TTY         TIME CMD
 0 S     root   824   386   0  40 020        ?    252        ?   Sep 06 console  0:00 /usr/lib/saf/ttymon -g -h
 -p mcdoug
 0 S     root   823   386   0  40 20        ?    242        ?   Sep 06 ?           0:00 /usr/lib/saf/sac -t 300
 0 S   nobody  1718   716   0  40 20        ?    834        ?   Sep 07 ?           0:35 /usr/apache/bin/httpd
 0 S     root   591   374   0  40 20        ?    478        ?   Sep 06 ?           0:00 /
usr/lib/autofs/automountd
 0 S     root   386   374   0  40 20        ?    262        ?   Sep 06 ?           0:01 init
 1 S     root   374   374   0   0 SY        ?      0        ?   Sep 06 ?           0:00 zsched
 0 S   daemon   490   374   0  40 20        ?    291        ?   Sep 06 ?           0:00 /usr/sbin/rpcbind
 0 S   daemon   435   374   0  40 20        ?    450        ?   Sep 06 ?           0:00 /usr/lib/crypto/kcfd
 0 S     root   603   374   0  40 20        ?    475        ?   Sep 06 ?           0:12 /usr/sbin/nscd
 0 S     root   580   374   0  40 20        ?    448        ?   Sep 06 ?           0:02 /usr/sbin/syslogd
 0 S     root   601   374   0  40 20        ?    313        ?   Sep 06 ?           0:00 /usr/sbin/cron
 0 S   daemon   548   374   0  40 20        ?    319        ?   Sep 06 ?           0:00 /usr/lib/nfs/statd
 0 S   daemon   550   374   0  40 20        ?    280        ?   Sep 06 ?           0:00 /usr/lib/nfs/lockd
 0 S     root   611   374   0  40 20        ?    329        ?   Sep 06 ?           0:00 /usr/sbin/inetd -s
 0 S     root   649   374   0  40 20        ?    152        ?   Sep 06 ?           0:00 /usr/lib/utmpd
 0 S   nobody   778   716   0  40 20        ?    835        ?   Sep 06 ?           0:26 /usr/apache/bin/httpd
 0 S     root   678   374   0  40 20        ?    612        ?   Sep 06 ?           0:00 /usr/dt/bin/dtlogin
 -daemon
```

System-wide Process View - prstat(1)

```
  PID USERNAME  SIZE   RSS STATE  PRI NICE      TIME  CPU PROCESS/NLWP
26292 root     5368K 3080K run     24    0   0:00:00 1.5% pkginstall/1
26188 rmc      4880K 4512K cpu0    49    0   0:00:00 0.6% prstat/1
  202 root     3304K 1800K sleep   59    0   0:00:07 0.3% nscd/24
23078 root       20M   14M sleep   59    0   0:00:56 0.2% lupi_zones/1
23860 root     5104K 2328K sleep   59    0   0:00:01 0.1% sshd/1
 ...
  365 root     4760K  128K sleep   59    0   0:00:00 0.0% zoneadmd/4
  364 root     4776K  128K sleep   59    0   0:00:00 0.0% zoneadmd/4
  374 root        0K    0K sleep   60    -   0:00:00 0.0% zsched/1
  361 root     2016K    8K sleep   59    0   0:00:00 0.0% ttymon/1
  349 root     8600K  616K sleep   59    0   0:00:20 0.0% snmpd/1
  386 root     2096K  360K sleep   59    0   0:00:00 0.0% init/1
  345 root     3160K  496K sleep   59    0   0:00:00 0.0% sshd/1
  591 root     3824K  184K sleep   59    0   0:00:00 0.0% automountd/2
  ....
  242 root     1896K    8K sleep   59    0   0:00:00 0.0% smcboot/1
  248 smmsp    4736K  696K sleep   59    0   0:00:08 0.0% sendmail/1
  245 root     1888K    0K sleep   59    0   0:00:00 0.0% smcboot/1
  824 root     2016K    8K sleep   59    0   0:00:00 0.0% ttymon/1
  204 root     2752K  536K sleep   59    0   0:00:00 0.0% inetd/1
  220 root     1568K    8K sleep   59    0   0:00:00 0.0% powerd/3
  313 root     2336K  216K sleep   59    0   0:00:00 0.0% snmpdx/1
  184 root     4312K  872K sleep   59    0   0:00:01 0.0% syslogd/13
  162 daemon   2240K   16K sleep   60  -20   0:00:00 0.0% lockd/2
Total: 126 processes, 311 lwps, load averages: 0.48, 0.48, 0.41
```

The Life Of A Process

- Process creation
  - > fork(2) system call creates all processes
    - > SIDL state
  - > exec(2) overlays newly created process with executable image
- State Transitions
  - > Typically runnable (SRUN), running (SONPROC) or sleeping (aka blocked, SSLEEP)
  - > Maybe stopped (debugger) SSTOP
- Termination
  - > SZOMB state
  - > implicit or explicit exit(), signal (kill), fatal error

Process Creation

- Traditional UNIX fork/exec model
  - fork(2) - replicate the entire process, including all threads
  - fork1(2) - replicate the process, only the calling thread
  - vfork(2) - replicate the process, but do not dup the address space
    - The new child borrows the parent's address space, until exec()

```
main(int argc, char *argv[])
{
        pid_t pid;
        pid = fork();
        if (pid == 0)   /* in the child */
                exec();
        else if (pid > 0)   /* in the parent */
                wait();
        else
                fork failed
}
```

fork(2) in Solaris 10

- Solaris 10 unified the process model
  - libthread merged with libc
  - threaded and non-threaded processes look the same
- fork(2) now replicates only the calling thread
  - Previously, fork1(2) needed to be called to do this
  - Linking with -lpthread in previous releases also resulted in fork1(2) behaviour
- forkall(2) added for applications that require a fork to replicate all the threads in the process

exec(2) – Load a new process image

- Most fork(2) calls are followed by an exec(2)
- exec – execute a new file
- exec overlays the process image with a new process constructed from the binary file passed as an arg to exec (2)
- The exec'd process inherits much of the caller's state:
  - nice value, scheduling class, priority, PID, PPID, GID, task ID, project ID, session membership, real UID & GID, current working directory, resource limits, processor binding, times, etc, ...

Process create example

C code calling fork()

```
#include <sys/types.h>
#include <unistd.h>

int main(int argc, char *argv[])
{
        pid_t   ret, cpid, ppid;

        ppid = getpid();
        ret = fork();
        if (ret == -1) {
                perror("fork");
                exit(0);
        } else if (ret == 0) {
                printf("In child...\n");
        } else {
                printf("Child PID: %d\n",ret);
        }
        exit(0);
}
```

D script to generate kernel trace

```
#!/usr/sbin/dtrace -Fs

syscall::fork1:entry
/ pid == $target /
{
        self->trace = 1;
}
fbt:::
/ self->trace /
{
}
syscall::fork1:return
/ pid == $target /
{
        self->trace = 0;
        exit(0);
}
```

Fork Kernel Trace

```
CPU FUNCTION
  0  -> fork1
  0  <- fork1
  0  -> cfork
  0    -> secpolicy_basic_fork
  0    <- secpolicy_basic_fork
  0    -> priv_policy
  0    <- priv_policy
  0    -> holdlwps
  0      -> schedctl_finish_sigblock
  0      <- schedctl_finish_sigblock
  0      -> pokelwps
  0      <- pokelwps
  0    <- holdlwps
  0    -> flush_user_windows_to_stack
  0    -> getproc
  0      -> page_mem_avail
  0      <- page_mem_avail
  0      -> zone_status_get
  0      <- zone_status_get
  0      -> kmem_cache_alloc
  0        -> kmem_cpu_reload
  0        <- kmem_cpu_reload
  0      <- kmem_cache_alloc
  0      -> pid_assign
  0        -> kmem_zalloc
  0          <- kmem_cache_alloc
  0        <- kmem_zalloc
  0        -> pid_lookup
  0        -> pid_getlockslot
  0      -> crgetruid
  0      -> crgetzoneid
  0      -> upcount_inc
  0        -> rctl_set_dup
                ...
  0          -> project_cpu_shares_set
  0          -> project_lwps_set
  0          -> project_ntasks_set
                ...
  0        <- rctl_set_dup
```

Fork Kernel Trace (cont)

```
0    -> as_dup
              ...
0        <- hat_alloc
0      <- as_alloc
0      -> seg_alloc
0      -> rctl_set_fill_alloc_gp
0    <- rctl_set_dup_ready
0    -> rctl_set_dup
              ...
0    -> forklwp
0      <- flush_user_windows_to_stack
0      -> save_syscall_args
0      -> lwp_create
0        <- thread_create
0        -> lwp_stk_init
0        -> kmem_zalloc
0      <- lwp_create
0      -> init_mstate
0      -> lwp_forkregs
0      -> forkctx
0      -> ts_alloc
0      -> ts_fork
0    <- forklwp
0    -> contract_process_fork
0    -> ts_forkret
0      -> continuelwps
0      -> ts_setrun
0      -> setbackdq
0      -> generic_enq_thread
0    <- ts_forkret
0    -> swtch
0      -> disp
0    <- swtch
0    -> resume
0      -> savectx
0      <- savectx
0      -> restorectx
0    <- resume
0  <- cfork
0  <= fork1
```

Watching Forks

D script for watching fork(2)

```
#!/usr/sbin/dtrace -qs

syscall::forkall:entry
{
        @fall[execname] = count();
}
syscall::fork1:entry
{
        @f1[execname] = count();
}
syscall::vfork:entry
{
        @vf[execname] = count();
}

dtrace:::END
{
        printf("forkall\n");
        printa(@fall);
        printf("fork1\n");
        printa(@f1);
        printf("vfork\n");
        printa(@vf);
}
```

Example run

```
# ./watchfork.d
^C
forkall

fork1

  start-srvr          1
  bash                3
  4cli                6
vfork
```

exec(2) – Load a new process image

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Watching exec(2) with DTrace

- The D script...

```
#pragma D option quiet
proc:::exec
{
        self->parent = execname;
}
proc:::exec-success
/self->parent != NULL/
{
        @[self->parent, execname] = count();
        self->parent = NULL;
}
proc:::exec-failure
/self->parent != NULL/
{
        self->parent = NULL;
}
END
{
        printf("%-20s %-20s %s\n", "WHO", "WHAT", "COUNT");
        printa("%-20s %-20s %@d\n", @);
}
```

Watching exec(2) with DTrace

- Example output:

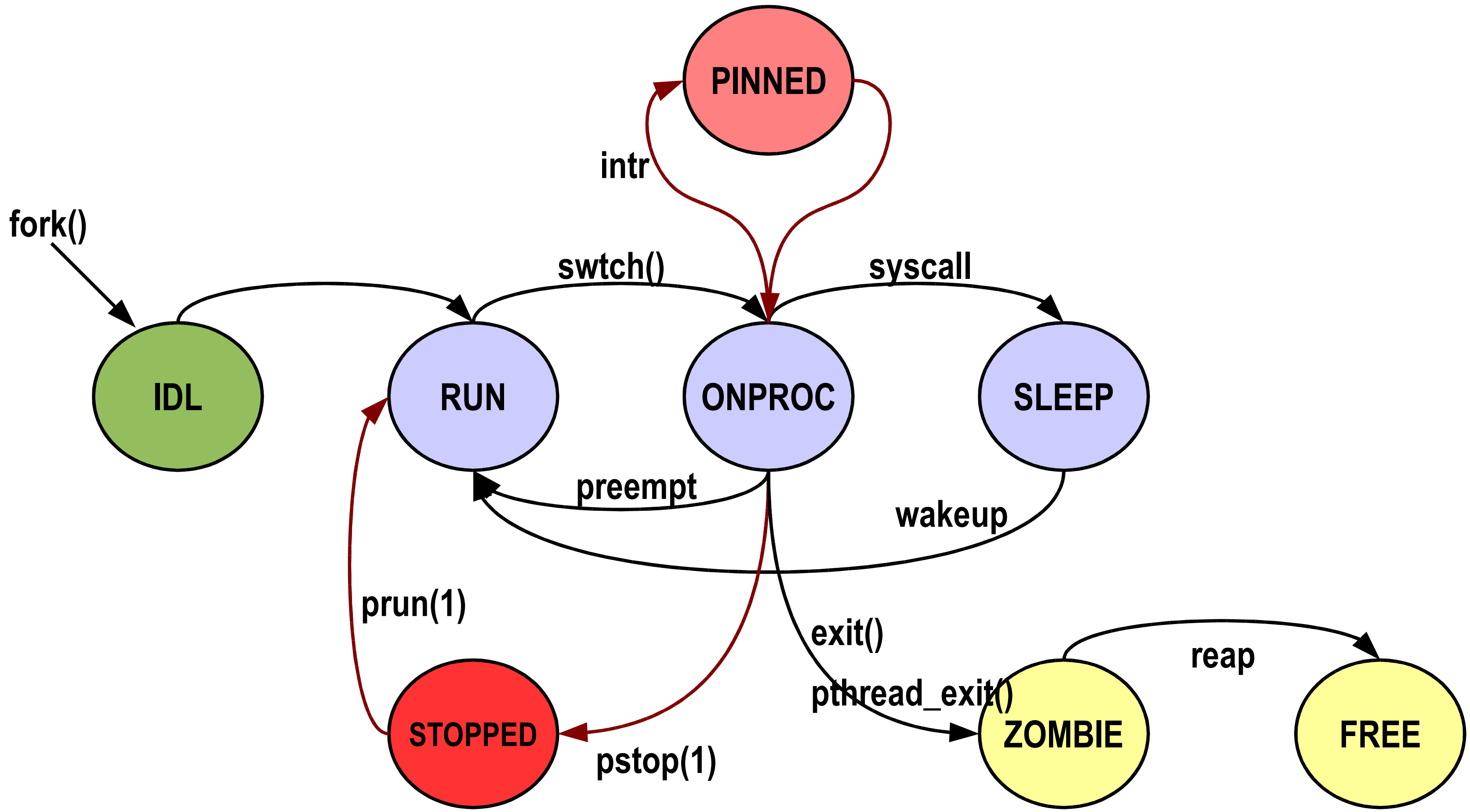
```
# dtrace -s ./whoexec.d
^C
WHO        WHAT       COUNT
make.bin   yacc       1
tcsh       make       1
make.bin   spec2map   1
sh         grep       1
lint       lint2      1
sh         lint       1
sh         ln         1
cc         ld         1
make.bin   cc         1
lint       lint1      1
```

Process / Thread States

- It's really kernel threads that change state
- Kernel thread creation is not flagged as a distinct state
  - Initial state is TS_RUN
- Kernel threads are TS_FREE when the process, or LWP/kthread, terminates

Process State	Kernel Thread State
SIDL	
SRUN	TS_RUN
SONPROC	TS_ONPROC
SSLEEP	TS_SLEEP
SSTOP	TS_STOPPED
SZOMB	TS_ZOMB
	TS_FREE

State Transitions



Watching Process States

```
  PID USERNAME  SIZE   RSS STATE  PRI NICE      TIME  CPU PROCESS/NLWP
27946 root     4880K 4520K cpu0    59    0   0:00:00 0.7% prstat/1
28010 root     4928K 2584K run     29    0   0:00:00 0.7% pkginstall/1
23078 root       20M   14M sleep   59    0   0:00:57 0.3% lupi_zones/1
25947 root     5160K 2976K sleep   59    0   0:00:04 0.3% sshd/1
24866 root     5136K 2136K sleep   59    0   0:00:01 0.2% sshd/1
  202 root     3304K 1800K sleep   59    0   0:00:09 0.2% nscd/24
23001 root     5136K 2176K sleep   59    0   0:00:04 0.1% sshd/1
23860 root     5248K 2392K sleep   59    0   0:00:05 0.1% sshd/1
25946 rmc      3008K 2184K sleep   59    0   0:00:02 0.1% ssh/1
25690 root     1240K  928K sleep   59    0   0:00:00 0.1% sh/1
 ...
  312 root     4912K   24K sleep   59    0   0:00:00 0.0% dtlogin/1
  250 root     4760K  696K sleep   59    0   0:00:16 0.0% sendmail/1
  246 root     1888K    0K sleep   59    0   0:00:00 0.0% smcboot/1
  823 root     1936K  224K sleep   59    0   0:00:00 0.0% sac/1
  242 root     1896K    8K sleep   59    0   0:00:00 0.0% smcboot/1
  248 smmsp    4736K  680K sleep   59    0   0:00:08 0.0% sendmail/1
  245 root     1888K    0K sleep   59    0   0:00:00 0.0% smcboot/1
  824 root     2016K    8K sleep   59    0   0:00:00 0.0% ttymon/1
  204 root     2752K  520K sleep   59    0   0:00:00 0.0% inetd/1
  220 root     1568K    8K sleep   59    0   0:00:00 0.0% powerd/3
  313 root     2336K  216K sleep   59    0   0:00:00 0.0% snmpdx/1
Total: 127 processes, 312 lwps, load averages: 0.62, 0.62, 0.53
```

Microstates

- Fine-grained state tracking for processes/threads
  - Off by default in Solaris 8 and Solaris 9
  - On by default in Solaris 10
- Can be enabled per-process via /proc
- prstat -m reports microstates
  - As a percentage of time for the sampling period
    - USR – user mode
    - SYS - kernel mode
    - TRP – trap handling
    - TFL – text page faults
    - DFL – data page faults
    - LCK – user lock wait
    - SLP - sleep
    - LAT – waiting for a processor (sitting on a run queue)

prstat – process microstates

```
sol8$ prstat -m
   PID USERNAME USR SYS TRP TFL DFL LCK SLP LAT VCX ICX SCL SIG PROCESS/NLWP
   739 root     0.3 0.3 0.0 0.0 0.0 0.0  99 0.0 126   3 345   5 Xsun/1
 15611 root     0.1 0.3 0.0 0.0 0.0 0.0 100 0.0  23   0 381   0 prstat/1
  1125 tlc      0.3 0.0 0.0 0.0 0.0 0.0 100 0.0  29   0 116   0 gnome-panel/1
 15553 rmc      0.1 0.2 0.0 0.0 0.0 0.0 100 0.0  24   0 381   0 prstat/1
  5591 tlc      0.1 0.0 0.0 0.0 0.0  33  66 0.0 206   0  1K   0 mozilla-bin/6
  1121 tlc      0.0 0.0 0.0 0.0 0.0 0.0 100 0.1  50   0 230   0 metacity/1
  2107 rmc      0.0 0.0 0.0 0.0 0.0 0.0 100 0.0  25   0  36   0 gnome-termin/1
   478 root     0.0 0.0 0.0 0.0 0.0 0.0 100 0.0  17   0  14   0 squid/1
   798 root     0.0 0.0 0.0 0.0 0.0 0.0 100 0.0  11   0  23   0 Xsun/1
  1145 tlc      0.0 0.0 0.0 0.0 0.0 0.0 100 0.0  25   1  34   0 mixer_applet/1
  1141 rmc      0.0 0.0 0.0 0.0 0.0 0.0 100 0.0  25   0  32   0 mixer_applet/1
  1119 tlc      0.0 0.0 0.0 0.0 0.0 0.0 100 0.0   5   0  40   0 gnome-smprox/1
  1127 tlc      0.0 0.0 0.0 0.0 0.0 0.0 100 0.0   7   0  29   0 nautilus/3
  1105 rmc      0.0 0.0 0.0 0.0 0.0 0.0 100 0.0   7   0  27   0 nautilus/3
   713 root     0.0 0.0 0.0 0.0 0.0  85  15 0.0   2   0 100   0 mibiisa/7
   174 root     0.0 0.0 0.0 0.0 0.0 0.0 100 0.0   5   0  50   5 ipmon/1
  1055 tlc      0.0 0.0 0.0 0.0 0.0 0.0 100 0.0   5   0  30   0 dsdm/1
Total: 163 processes, 275 lwps, load averages: 0.07, 0.07, 0.07
```

prstat – user summary

```
sol8$ prstat -t
NPROC USERNAME  SIZE   RSS MEMORY      TIME  CPU
  128 root      446M  333M   1.4%  47:14:23  11%
    2 measter  6600K 5016K   0.0%   0:00:07 0.2%
    1 clamb    9152K 8344K   0.0%   0:02:14 0.1%
    2 rmc      7192K 6440K   0.0%   0:00:00 0.1%
    1 bricker  5776K 4952K   0.0%   0:00:20 0.1%
    2 asd        10M 8696K   0.0%   0:00:01 0.1%
    1 fredz    7760K 6944K   0.0%   0:00:05 0.1%
    2 jenks    8576K 6904K   0.0%   0:00:01 0.1%
    1 muffin     15M   14M   0.1%   0:01:26 0.1%
    1 dte      3800K 3016K   0.0%   0:00:04 0.0%
    2 adjg     8672K 7040K   0.0%   0:00:03 0.0%
    3 msw        14M   10M   0.0%   0:00:00 0.0%
    1 welza    4032K 3248K   0.0%   0:00:29 0.0%
    2 kimc     7848K 6344K   0.0%   0:00:25 0.0%
    4 jcmartin   13M 9904K   0.0%   0:00:03 0.0%
    1 rascal     17M   16M   0.1%   0:02:11 0.0%
    1 rab      3288K 2632K   0.0%   0:02:11 0.0%
    1 gjmurphy 3232K 2392K   0.0%   0:00:00 0.0%
    1 ktheisen   15M   14M   0.1%   0:01:16 0.0%
    1 nagendra 3232K 2400K   0.0%   0:00:00 0.0%
    2 ayong    8320K 6832K   0.0%   0:00:02 0.0%
Total: 711 processes, 902 lwps, load averages: 3.84, 4.30, 4.37
```

Solaris 8 ptools

```
/usr/bin/pflags [ -r ]  [ pid | core ]  ...
/usr/bin/pcred [ pid | core ]  ...
/usr/bin/pmap [ -rxlF ]  [ pid | core ]  ...
/usr/bin/pldd [ -F ]  [ pid | core ]  ...
/usr/bin/psig pid ...
/usr/bin/pstack [ -F ]  [ pid | core ]  ...
/usr/bin/pfiles [ -F ]  pid ...
/usr/bin/pwdx [ -F ]  pid ...
/usr/bin/pstop pid ...
/usr/bin/prun pid ..
/usr/bin/pwait [ -v ]  pid ...
/usr/bin/ptree [ -a ]  [  [ pid | user ]  ... ]
/usr/bin/ptime command  [ arg ... ]
/usr/bin/pgrep  [  -flnvx ]   [  -d delim   ]   [ -P ppidlist  ]
[ -g pgrplist ]  [ -s sidlist ]  [ -u euidlist ]  [ -U uidlist ]
[ -G gidlist ]  [ -J projidlist ]  [  -t termlist   ]   [ -T
taskidlist ]  [ pattern ]
/usr/bin/pkill [ -signal ]   [ -fnvx ]  [ -P ppidlist ]  [ -g
pgrplist ]   [  -s sidlist   ]   [ -u euidlist  ]  [ -U uidlist]
[ -G gidlist  ]   [  -J projidlist ]   [ -t termlist  ]   [-T
taskidlist ]  [ pattern ]
```

Solaris 9 / 10 ptools

```
/usr/bin/pflags [-r] [pid | core] ...
/usr/bin/pcred [pid | core] ...
/usr/bin/pldd [-F] [pid | core] ...
/usr/bin/psig [-n] pid...
/usr/bin/pstack [-F] [pid | core] ...
/usr/bin/pfiles [-F] pid...
/usr/bin/pwdx [-F] pid...
/usr/bin/pstop pid...
/usr/bin/prun pid...
/usr/bin/pwait [-v] pid...
/usr/bin/ptree [-a] [pid | user] ...
/usr/bin/ptime command [arg...]
/usr/bin/pmap -[xS] [-rslF] [pid | core] ...
/usr/bin/pgrep  [-flvx]  [-n  |  -o]   [-d delim] [-P ppidlist]  [-
g pgrplist]   [-s sidlist]    [-u euidlist]   [-U uidlist]  [-
G gidlist]  [-J projidlist]  [-t termlist]   [-T taskidlist]
[pattern]
/usr/bin/pkill  [-signal] [-fvx] [-n  |  -o] [-P ppidlist]  [-
g pgrplist]   [-s sidlist]    [-u euidlist]   [-U uidlist]  [-
G gidlist]  [-J projidlist]  [-t termlist]   [-T taskidlist]
[pattern]
/usr/bin/plimit [-km] pid...
{-cdfnstv} soft,hard... pid...
/usr/bin/ppgsz  [-F] -o option[,option]  cmd | -p pid...
/usr/bin/prctl [-t [basic | privileged | system] ] [ -e | -d  action]
[-rx] [ -n name [-v value]] [-i idtype] [id...]
/usr/bin/preap [-F] pid
/usr/bin/pargs [-aceFx] [pid | core] ...
```

pflags, pcred, pldd

```
sol8# pflags $$
482764: -ksh
  data model = _ILP32  flags = PR_ORPHAN
  /1:  flags = PR_PCINVAL|PR_ASLEEP [ waitid(0x7,0x0,0xffbff938,0x7) ]


sol8$ pcred $$
482764: e/r/suid=36413  e/r/sgid=10
  groups: 10 10512 570

sol8$ pldd $$
482764: -ksh
/usr/lib/libsocket.so.1
/usr/lib/libnsl.so.1
/usr/lib/libc.so.1
/usr/lib/libdl.so.1
/usr/lib/libmp.so.2
```

psig

```
sol8$ psig $$
15481: -zsh
HUP  caught 0
INT  blocked,caught 0
QUIT blocked,ignored
ILL  blocked,default
TRAP blocked,default
ABRT blocked,default
EMT  blocked,default
FPE  blocked,default
KILL default
BUS  blocked,default
SEGV blocked,default
SYS  blocked,default
PIPE blocked,default
ALRM blocked,caught 0
TERM blocked,ignored
USR1 blocked,default
USR2 blocked,default
CLD  caught 0
PWR  blocked,default
WINCH  blocked,caught 0
URG  blocked,default
POLL blocked,default
STOP default
```

pstack

```
sol8$ pstack 5591
5591:  /usr/local/mozilla/mozilla-bin
-----------------  lwp# 1 / thread# 1  --------------------
 fe99a254 poll    (513d530, 4, 18)
 fe8dda58 poll    (513d530, fe8f75a8, 18, 4, 513d530, ffbeed00) + 5c
 fec38414 g_main_poll (18, 0, 0, 27c730, 0, 0) + 30c
 fec37608 g_main_iterate (1, 1, 1, ff2a01d4, ff3e2628, fe4761c9) + 7c0
 fec37e6c g_main_run (27c740, 27c740, 1, fe482b30, 0, 0) + fc
 fee67a84 gtk_main (b7a40, fe482874, 27c720, fe49c9c4, 0, 0) + 1bc
 fe482aa4 ???????? (d6490, fe482a6c, d6490, ff179ee4, 0, ffe)
 fe4e5518 ???????? (db010, fe4e5504, db010, fe4e6640, ffbeeed0, 1cf10)
 00019ae8 ???????? (0, ff1c02b0, 5fca8, 1b364, 100d4, 0)
 0001a4cc main    (0, ffbef144, ffbef14c, 5f320, 0, 0) + 160
 00014a38 _start   (0, 0, 0, 0, 0, 0) + 5c
-----------------  lwp# 2 / thread# 2  --------------------
 fe99a254 poll    (fe1afbd0, 2, 88b8)
 fe8dda58 poll    (fe1afbd0, fe840000, 88b8, 2, fe1afbd0, 568) + 5c
 ff0542d4 ???????? (75778, 2, 3567e0, b97de891, 4151f30, 0)
 ff05449c PR_Poll  (75778, 2, 3567e0, 0, 0, 0) + c
 fe652bac ???????? (75708, 80470007, 7570c, fe8f6000, 0, 0)
 ff13b5f0 Main__8nsThreadPv (f12f8, ff13b5c8, 0, 0, 0, 0) + 28
 ff055778 ???????? (f5588, fe840000, 0, 0, 0, 0)
 fe8e4934 _lwp_start (0, 0, 0, 0, 0, 0)
```

pfiles

```
sol8$ pfiles $$
pfiles $$
15481: -zsh
  Current rlimit: 256 file descriptors
   0: S_IFCHR mode:0620 dev:118,0 ino:459678 uid:36413 gid:7 rdev:24,11
      O_RDWR
   1: S_IFCHR mode:0620 dev:118,0 ino:459678 uid:36413 gid:7 rdev:24,11
  O_RDWR
   2: S_IFCHR mode:0620 dev:118,0 ino:459678 uid:36413 gid:7 rdev:24,11
  O_RDWR
   3: S_IFDOOR mode:0444 dev:250,0 ino:51008 uid:0 gid:0 size:0
  O_RDONLY|O_LARGEFILE FD_CLOEXEC  door to nscd[328]
  10: S_IFCHR mode:0620 dev:118,0 ino:459678 uid:36413 gid:7 rdev:24,11
  O_RDWR|O_LARGEFILE
```

pwdx, pstop, pwait, ptree

```
sol8$ pwdx $$
15481: /home/rmc
```

```
sol8$ pstop $$
[argh!]
```

```
sol8$ pwait 23141
```

```
sol8$ ptree $$
285   /usr/sbin/inetd -ts
    15554 in.rlogind
      15556 -zsh
    15562 ksh
    15657 ptree 15562
```

pgrep

```
sol8$ pgrep -u rmc
481
480
478
482
483
484
.....
```

Tracing

- Trace user signals and system calls - truss
  - Traces by stopping and starting the process
  - Can trace system calls, inline or as a summary
  - Can also trace shared libraries and a.out
- Linker/library interposing/profiling/tracing
  - LD_ environment variables enable link debugging
  - man ld.so.1
  - using the LD_PRELOAD env variable
- Trace Normal Formal (TNF)
  - Kernel and Process Tracing
  - Lock Tracing
- Kernel Tracing
  - lockstat, tnf, kgmon

Process Tracing – Truss

```
# truss -d dd if=500m of=/dev/null bs=16k count=2k 2>&1 |more
Base time stamp:  925931550.0927  [ Wed May  5 12:12:30 PDT 1999 ]
 0.0000 execve("/usr/bin/dd", 0xFFBEF68C, 0xFFBEF6A4)  argc = 5
 0.0034 open("/dev/zero", O_RDONLY)                   = 3
 0.0039 mmap(0x00000000, 8192, PROT_READ|PROT_WRITE|PROT_EXEC, MAP_PRIVATE, 3, 0) = 0xFF3A0000
 0.0043 open("/usr/lib/libc.so.1", O_RDONLY)          = 4
 0.0047 fstat(4, 0xFFBEF224)                          = 0
 0.0049 mmap(0x00000000, 8192, PROT_READ|PROT_EXEC, MAP_PRIVATE, 4, 0) = 0xFF390000
 0.0051 mmap(0x00000000, 761856, PROT_READ|PROT_EXEC, MAP_PRIVATE, 4, 0) = 0xFF280000
 0.0054 munmap(0xFF324000, 57344)                     = 0
 0.0057 mmap(0xFF332000, 25284, PROT_READ|PROT_WRITE|PROT_EXEC, MAP_PRIVATE|MAP_FIXED, 4, 663552) = 0xFF332000
 0.0062 close(4)                                      = 0
 0.0065 open("/usr/lib/libdl.so.1", O_RDONLY)         = 4
 0.0068 fstat(4, 0xFFBEF224)                          = 0
 0.0070 mmap(0xFF390000, 8192, PROT_READ|PROT_EXEC, MAP_PRIVATE|MAP_FIXED, 4, 0) = 0xFF390000
 0.0073 close(4)                                      = 0
 0.0076 open("/usr/platform/SUNW,Ultra-2/lib/libc_psr.so.1", O_RDONLY) = 4
 0.0079 fstat(4, 0xFFBEF004)                          = 0
 0.0082 mmap(0x00000000, 8192, PROT_READ|PROT_EXEC, MAP_PRIVATE, 4, 0) = 0xFF380000
 0.0084 mmap(0x00000000, 16384, PROT_READ|PROT_EXEC, MAP_PRIVATE, 4, 0) = 0xFF370000
 0.0087 close(4)                                      = 0
 0.0100 close(3)                                      = 0
 0.0103 munmap(0xFF380000, 8192)                      = 0
 0.0110 open64("500m", O_RDONLY)                      = 3
 0.0115 creat64("/dev/null", 0666)                    = 4
 0.0119 sysconfig(_CONFIG_PAGESIZE)                   = 8192
 0.0121 brk(0x00023F40)                               = 0
 0.0123 brk(0x0002BF40)                               = 0
 0.0127 sigaction(SIGINT, 0xFFBEF470, 0xFFBEF4F0)     = 0
 0.0129 sigaction(SIGINT, 0xFFBEF470, 0xFFBEF4F0)     = 0
 0.0134 read(3, "\0\0\0\0\0\0\0\0\0\0\0\0\0".., 16384)   = 16384
 0.0137 write(4, "\0\0\0\0\0\0\0\0\0\0\0\0\0".., 16384)  = 16384
 0.0140 read(3, "\0\0\0\0\0\0\0\0\0\0\0\0\0".., 16384)   = 16384
 0.0143 write(4, "\0\0\0\0\0\0\0\0\0\0\0\0\0".., 16384)  = 16384
 0.0146 read(3, "\0\0\0\0\0\0\0\0\0\0\0\0\0".., 16384)   = 16384
 0.0149 write(4, "\0\0\0\0\0\0\0\0\0\0\0\0\0".., 16384)  = 16384
 0.0152 read(3, "\0\0\0\0\0\0\0\0\0\0\0\0\0".., 16384)   = 16384
 0.0154 write(4, "\0\0\0\0\0\0\0\0\0\0\0\0\0".., 16384)  = 16384
```

Process Tracing – System Call Summary

- Counts total cpu seconds per system call and calls

```
# truss -c dd if=500m of=/dev/null bs=16k count=2k
syscall          seconds   calls  errors
_exit                .00       1
read                 .34    2048
write                .03    2056
open                 .00       4
close                .00       6
brk                  .00       2
fstat                .00       3
execve               .00       1
sigaction            .00       2
mmap                 .00       7
munmap               .00       2
sysconfig            .00       1
llseek               .00       1
creat64              .00       1
open64               .00       1
                    ----     ---     ---
sys totals:          .37    4136       0
usr time:            .00
elapsed:             .89
```

Library Tracing - truss -u

```
# truss -d -u a.out,libc dd if=500m of=/dev/null bs=16k count=2k
Base time stamp:  925932005.2498  [ Wed May  5 12:20:05 PDT 1999 ]
 0.0000 execve("/usr/bin/dd", 0xFFBEF68C, 0xFFBEF6A4)  argc = 5
 0.0073 open("/dev/zero", O_RDONLY)                  = 3
 0.0077 mmap(0x00000000, 8192, PROT_READ|PROT_WRITE|PROT_EXEC, MAP_PRIVATE, 3, 0) = 0xFF3A0000
 0.0094 open("/usr/lib/libc.so.1", O_RDONLY)          = 4
 0.0097 fstat(4, 0xFFBEF224)                          = 0
 0.0100 mmap(0x00000000, 8192, PROT_READ|PROT_EXEC, MAP_PRIVATE, 4, 0) = 0xFF390000
 0.0102 mmap(0x00000000, 761856, PROT_READ|PROT_EXEC, MAP_PRIVATE, 4, 0) = 0xFF280000
 0.0105 munmap(0xFF324000, 57344)                     = 0
 0.0107 mmap(0xFF332000, 25284, PROT_READ|PROT_WRITE|PROT_EXEC, MAP_PRIVATE|MAP_FIXED, 4, 663552) = 0xFF332000
 0.0113 close(4)                                      = 0
 0.0116 open("/usr/lib/libdl.so.1", O_RDONLY)         = 4
 0.0119 fstat(4, 0xFFBEF224)                          = 0
 0.0121 mmap(0xFF390000, 8192, PROT_READ|PROT_EXEC, MAP_PRIVATE|MAP_FIXED, 4, 0) = 0xFF390000
 0.0124 close(4)                                      = 0
 0.0127 open("/usr/platform/SUNW,Ultra-2/lib/libc_psr.so.1", O_RDONLY) = 4
 0.0131 fstat(4, 0xFFBEF004)                          = 0
 0.0133 mmap(0x00000000, 8192, PROT_READ|PROT_EXEC, MAP_PRIVATE, 4, 0) = 0xFF380000
 0.0135 mmap(0x00000000, 16384, PROT_READ|PROT_EXEC, MAP_PRIVATE, 4, 0) = 0xFF370000
 0.0138 close(4)                                      = 0
 0.2369 close(3)                                      = 0
 0.2372 munmap(0xFF380000, 8192)                      = 0
 0.2380 -> libc:atexit(0xff3b9e8c, 0x23400, 0x0, 0x0)
 0.2398 <- libc:atexit() = 0
 0.2403 -> libc:atexit(0x12ed4, 0xff3b9e8c, 0xff334518, 0xff332018)
 0.2419 <- libc:atexit() = 0
 0.2424 -> _init(0x0, 0x12ed4, 0xff334518, 0xff332018)
 0.2431 <- _init() = 0
 0.2436 -> main(0x5, 0xffbef68c, 0xffbef6a4, 0x23400)
 0.2443   -> libc:setlocale(0x6, 0x12f14, 0x0, 0x0)
 0.2585   <- libc:setlocale() = 0xff31f316
```

Library Tracing – apptrace(1)

```
sunsys> apptrace ls
ls       -> libc.so.1:atexit(func = 0xff3caa24) = 0x0
ls       -> libc.so.1:atexit(func = 0x13ad4) = 0x0
ls       -> libc.so.1:setlocale(category = 0x6, locale = "") = "/en_US.ISO8859-1/en_"
ls       -> libc.so.1:textdomain(domainname = "SUNW_OST_OSCMD") = "SUNW_OST_OSCMD"
ls       -> libc.so.1:time(tloc = 0x0) = 0x3aee2678
ls       -> libc.so.1:isatty(fildes = 0x1) = 0x1
ls       -> libc.so.1:getopt(argc = 0x1, argv = 0xffbeeff4, optstring =
                                    "RaAdC1xmnlogrtucpFbq") = 0xffffffff errno = 0 (Error 0)
ls       -> libc.so.1:getenv(name = "COLUMNS") = "<nil>"
ls       -> libc.so.1:ioctl(0x1, 0x5468, 0x2472a)
ls       -> libc.so.1:malloc(size = 0x100) = 0x25d10
ls       -> libc.so.1:malloc(size = 0x9000) = 0x25e18
ls       -> libc.so.1:lstat64(path = ".", buf = 0xffbeee98) = 0x0
ls       -> libc.so.1:qsort(base = 0x25d10, nel = 0x1, width = 0x4, compar = 0x134bc)
ls       -> libc.so.1:.div(0x50, 0x3, 0x50)
ls       -> libc.so.1:.div(0xffffffff, 0x1a, 0x0)
ls       -> libc.so.1:.mul(0x1, 0x0, 0xffffffff)
ls       -> libc.so.1:.mul(0x1, 0x1, 0x0)
```

User Threads

- The programming abstraction for creating multithreaded programs
  - Parallelism
  - POSIX and UI thread APIs
    - thr_create(3THR)
    - pthread_create(3THR)
  - Synchronization
    - Mutex locks, reader/writer locks, semaphores, condition variables
- Solaris 2 originally implemented an MxN threads model (T1)
  - “unbound” threads
- Solaris 8 introduced the 1 level model (T2)
  - /usr/lib/lwp/libthread.so
- T2 is the default in Solaris 9 and Solaris 10

Threads Primer Example:

```
#include <pthread.h>
#include <stdio.h>
mutex_t mem_lock;
void childthread(void *argument)
{
     int i;
     for(i = 1; i <= 100; ++i) {
          print("Child Count - %d\n", i);
     }
     pthread_exit(0);
 }
int main(void)
{
     pthread_t thread, thread2;
     int ret;

     if ((pthread_create(&thread, NULL, (void *)childthread, NULL)) < 0) {
          printf ("Thread Creation Failed\n");
          return (1);
     }
     pthread_join(thread,NULL);
     print("Parent is continuing....\n");
     return (0);
}
```

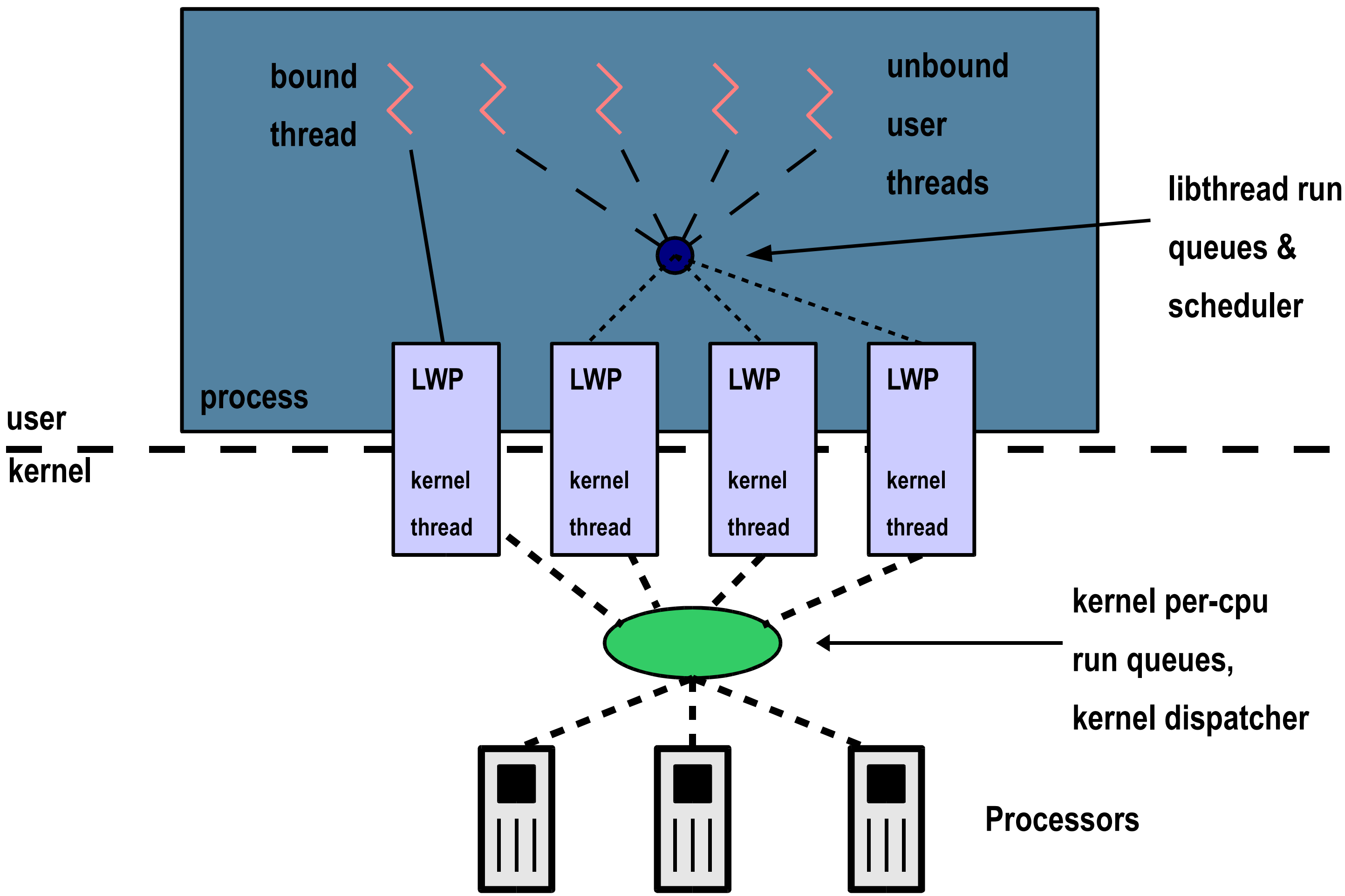
T1 – Multilevel MxN Model

- /usr/lib/libthread.so.1
- Based on the assumption that kernel threads are expensive, user threads are cheap.
- User threads are virtualized, and may be multiplexed onto one or more kernel threads
  - LWP pool
- User level thread synchronization - threads sleep at user level. (Process private only)
- Concurrency via set_concurrency() and bound LWPs

T1 – Multilevel Model

- Unbound Thread Implementation
  - > User Level scheduling
  - > Unbound threads switched onto available lwps
  - > Threads switched when blocked on sync object
  - > Thread temporary bound when blocked in system call
  - > Daemon lwp to create new lwps
  - > Signal direction handled by Daemon lwp
  - > Reaper thread to manage cleanup
  - > Callout lwp for timers

T1- Multilevel Model
(default in Solaris 8)



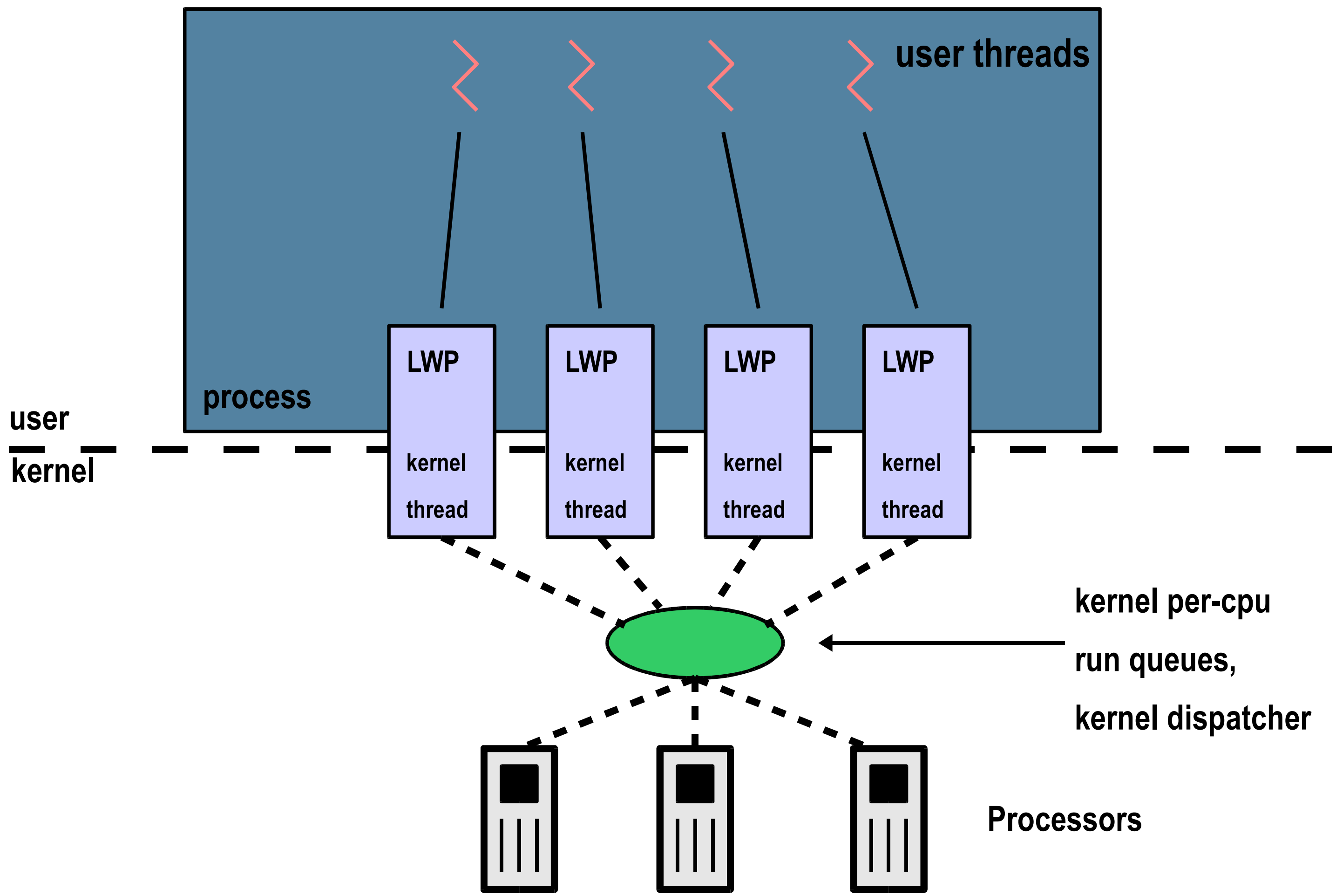
T1 – Multilevel Model

- Pros:
  - > Fast user thread create and destroy
  - > Allows many-to-few thread model, to mimimize the number of kernel threads and LWPs
  - > Uses minimal kernel memory
  - > No system call required for synchronization
  - > Process Private Synchronization only
  - > Can have thousands of threads
  - > Fast context-switching
- Cons:
  - > Complex, and tricky programming model wrt achieving good scalability - need to bind or use set_concurrency()
  - > Signal delivery
  - > Compute bound threads do not surrender, leading to excessive CPU consumption and potential starving
  - > Complex to maintain (for Sun)

T2 – Single Level Threads Model

- All user threads bound to LWPs
  - All bound threads
- Kernel level scheduling
  - No more libthread.so scheduler
- Simplified Implementation
- Uses kernel's synchronization objects
  - Slightly different behaviour LIFO vs. FIFO
  - Allows adaptive lock behaviour
- More expensive thread create/destroy, synchronization
- More responsive scheduling, synchronization

T2 – Single Level Threads Model



T2 - Single Level Thread Model

- Scheduling wrt Synchronization (S8U7/S9/S10)
  - Adaptive locks give preference to a thread that is running, potentially at the expense of a thread that is sleeping
  - Threads that rely on fairness of scheduling/CPU could end up ping-ponging, at the expense of another thread which has work to do.
- Default S8U7/S9/S10 Behaviour
  - Adaptive Spin
    - 1000 of iterations (spin count) for adaptive mutex locking before giving up and going to sleep.
  - Maximum number of spinners
    - The number of simultaneously spinning threads
    - attempting to do adaptive locking on one mutex is limited to 100.
  - One out of every 16 queuing operations will put a thread at the end of the queue, to prevent starvation.
  - Stack Cache
    - The maximum number of stacks the library retains after threads exit for re-use when more threads are created is 10.

Thread Semantics Added to pstack, truss

```
# pstack 909/2
909:    dbwr -a dbwr -i 2 -s b0000000 -m /var/tmp/fbencAAAmxaqxb
-----------------  lwp# 2  --------------------------------
 ceab1809 lwp_park (0, afffde50, 0)
 ceaabf93 cond_wait_queue (ce9f8378, ce9f83a0, afffde50, 0) + 3b
 ceaac33f cond_wait_common (ce9f8378, ce9f83a0, afffde50) + 1df
 ceaac686 _cond_reltimedwait (ce9f8378, ce9f83a0, afffdea0) + 36
 ceaac6b4 cond_reltimedwait (ce9f8378, ce9f83a0, afffdea0) + 24
 ce9e5902 __aio_waitn (82d1f08, 1000, afffdf2c, afffdf18, 1) + 529
 ceaf2a84 aio_waitn64 (82d1f08, 1000, afffdf2c, afffdf18) + 24
 08063065 flowoplib_aiowait (b4eb475c, c40f4d54) + 97
 08061de1 flowop_start (b4eb475c) + 257
 ceab15c0 _thr_setup (ce9a8400) + 50
 ceab1780 _lwp_start (ce9a8400, 0, 0, afffdff8, ceab1780, ce9a8400)
```

```
pae1> truss -p 2975/3
/3:   close(5)                                  = 0
/3:   open("/space1/3", O_RDWR|O_CREAT, 0666)         = 5
/3:   lseek(5, 0, SEEK_SET)                               = 0
/3:   write(5, " U U U U U U U U U U U U".., 1056768)    = 1056768
/3:   lseek(5, 0, SEEK_SET)                               = 0
/3:   read(5, " U U U U U U U U U U U U".., 1056768)     = 1056768
/3:   close(5)                                  = 0
/3:   open("/space1/3", O_RDWR|O_CREAT, 0666)         = 5
/3:   lseek(5, 0, SEEK_SET)                               = 0
/3:   write(5, " U U U U U U U U U U U U".., 1056768)    = 1056768
```

Thread Microstates

```
   PID USERNAME USR SYS TRP TFL DFL LCK SLP LAT VCX ICX SCL SIG PROCESS/LWPID
   918 rmc      0.2 0.4 0.0 0.0 0.0 0.0  99 0.0  27   2  1K   0 prstat/1
   919 mauroj   0.1 0.4 0.0 0.0 0.0 0.0  99 0.1  44  12  1K   0 prstat/1
   907 root     0.0 0.1 0.0 0.0 0.0 0.0  97 3.1 121   2  20   0 filebench/2
   913 root     0.1 0.0 0.0 0.0 0.0 100 0.0 0.0  15   2 420   0 filebench/2
   866 root     0.0 0.0 0.0 0.0 0.0 0.0  96 4.1  44  41 398   0 filebench/2
   820 root     0.0 0.0 0.0 0.0 0.0 0.0  95 5.0  43  42 424   0 filebench/2
   814 root     0.0 0.0 0.0 0.0 0.0 0.0  95 5.0  43  41 424   0 filebench/2
   772 root     0.0 0.0 0.0 0.0 0.0 0.0  96 3.6  46  39 398   0 filebench/2
   749 root     0.0 0.0 0.0 0.0 0.0 0.0  96 3.7  45  41 398   0 filebench/2
   744 root     0.0 0.0 0.0 0.0 0.0 0.0  95 4.7  47  39 398   0 filebench/2
   859 root     0.0 0.0 0.0 0.0 0.0 0.0  95 4.9  44  41 424   0 filebench/2
   837 root     0.0 0.0 0.0 0.0 0.0 0.0  96 4.0  43  43 405   0 filebench/2
  [snip]
   787 root     0.0 0.0 0.0 0.0 0.0 0.0  95 4.5  43  41 424   0 filebench/2
   776 root     0.0 0.0 0.0 0.0 0.0 0.0  95 4.8  43  42 398   0 filebench/2
   774 root     0.0 0.0 0.0 0.0 0.0 0.0  96 4.2  43  40 398   0 filebench/2
   756 root     0.0 0.0 0.0 0.0 0.0 0.0  96 3.8  44  41 398   0 filebench/2
   738 root     0.0 0.0 0.0 0.0 0.0 0.0  96 4.4  43  42 398   0 filebench/2
   735 root     0.0 0.0 0.0 0.0 0.0 0.0  96 3.9  47  39 405   0 filebench/2
   734 root     0.0 0.0 0.0 0.0 0.0 0.0  96 4.3  44  41 398   0 filebench/2
   727 root     0.0 0.0 0.0 0.0 0.0 0.0  96 4.4  43  43 398   0 filebench/2
   725 root     0.0 0.0 0.0 0.0 0.0 0.0  96 4.4  43  43 398   0 filebench/2
Total: 257 processes, 3139 lwps, load averages: 7.71, 2.39, 0.97
```

Watching Threads

```
  PID USERNAME  SIZE   RSS STATE  PRI NICE      TIME  CPU PROCESS/LWPID
29105 root     5400K 3032K sleep   60    0   0:00:00 1.3% pkginstall/1
29051 root     5072K 4768K cpu0    49    0   0:00:00 0.8% prstat/1
  202 root     3304K 1256K sleep   59    0   0:00:07 0.3% nscd/23
25947 root     5160K  608K sleep   59    0   0:00:05 0.2% sshd/1
23078 root       20M 1880K sleep   59    0   0:00:58 0.2% lupi_zones/1
25946 rmc      3008K  624K sleep   59    0   0:00:02 0.2% ssh/1
23860 root     5248K  688K sleep   59    0   0:00:06 0.2% sshd/1
29100 root     1272K  976K sleep   59    0   0:00:00 0.1% mpstat/1
24866 root     5136K  600K sleep   59    0   0:00:02 0.0% sshd/1
  340 root     2504K  672K sleep   59    0   0:11:14 0.0% mibiisa/2
23001 root     5136K  584K sleep   59    0   0:00:04 0.0% sshd/1
  830 root     2472K  600K sleep   59    0   0:11:01 0.0% mibiisa/2
  829 root     2488K  648K sleep   59    0   0:11:01 0.0% mibiisa/2
    1 root     2184K  400K sleep   59    0   0:00:01 0.0% init/1
  202 root     3304K 1256K sleep   59    0   0:00:00 0.0% nscd/13
  202 root     3304K 1256K sleep   59    0   0:00:00 0.0% nscd/12
  202 root     3304K 1256K sleep   59    0   0:00:00 0.0% nscd/11
  202 root     3304K 1256K sleep   59    0   0:00:00 0.0% nscd/10
  202 root     3304K 1256K sleep   59    0   0:00:00 0.0% nscd/9
  202 root     3304K 1256K sleep   59    0   0:00:00 0.0% nscd/8
  202 root     3304K 1256K sleep   59    0   0:00:00 0.0% nscd/7
  202 root     3304K 1256K sleep   59    0   0:00:00 0.0% nscd/6
  202 root     3304K 1256K sleep   59    0   0:00:00 0.0% nscd/5
  202 root     3304K 1256K sleep   59    0   0:00:00 0.0% nscd/4
  202 root     3304K 1256K sleep   59    0   0:00:00 0.0% nscd/3
  202 root     3304K 1256K sleep   59    0   0:00:00 0.0% nscd/2
  202 root     3304K 1256K sleep   59    0   0:00:00 0.0% nscd/1
  126 daemon   2360K    8K sleep   59    0   0:00:00 0.0% rpcbind/1
  814 root     1936K  280K sleep   59    0   0:00:00 0.0% sac/1
   64 root     2952K    8K sleep   59    0   0:00:00 0.0% picld/5
   64 root     2952K    8K sleep   59    0   0:00:00 0.0% picld/4
   64 root     2952K    8K sleep   59    0   0:00:00 0.0% picld/3
   64 root     2952K    8K sleep   59    0   0:00:00 0.0% picld/2
   64 root     2952K    8K sleep   59    0   0:00:00 0.0% picld/1
   61 daemon   3640K    8K sleep   59    0   0:00:00 0.0% kcfd/3
   61 daemon   3640K    8K sleep   59    0   0:00:00 0.0% kcfd/2
   61 daemon   3640K    8K sleep   59    0   0:00:00 0.0% kcfd/1
   55 root     2416K    8K sleep   59    0   0:00:00 0.0% syseventd/14
   55 root     2416K    8K sleep   59    0   0:00:00 0.0% syseventd/13
   55 root     2416K    8K sleep   59    0   0:00:00 0.0% syseventd/12
   55 root     2416K    8K sleep   59    0   0:00:00 0.0% syseventd/11
Total: 125 processes, 310 lwps, load averages: 0.50, 0.38, 0.40
```

Examining A Thread Structure

```
# mdb -k
Loading modules: [ unix krtld genunix specfs dtrace ufs ip sctp usba fctl nca lofs nfs random sppp
crypto ptm logindmux cpc ]
> ::ps
S    PID   PPID   PGID    SID    UID      FLAGS             ADDR NAME
R      0      0      0      0      0 0x00000001 fffffffffbc1ce80 sched
R      3      0      0      0      0 0x00020001 ffffffff880838f8 fsflush
R      2      0      0      0      0 0x00020001 ffffffff88084520 pageout
R      1      0      0      0      0 0x42004000 ffffffff88085148 init
R  21344      1  21343  21280   2234 0x42004000 ffffffff95549938 tcpPerfServer
> ffffffff95549938::print proc_t
{
    p_exec = 0xffffffff9285dc40
    p_as = 0xffffffff87c776c8
        ...
    p_tlist = 0xffffffff8826bc20
        ...
> ffffffff8826bc20::print kthread_t
{
    t_link = 0
    t_stk = 0xfffffe8000161f20
    t_startpc = 0
    t_bound_cpu = 0
    t_affinitycnt = 0
    t_bind_cpu = 0xffff
    t_cid = 0x1
    t_clfuncs = ts_classfuncs+0x48
    t_cldata = 0xffffffffa5f0b2a8
    t_cpu = 0xffffffff87c80800
    t_lbolt = 0x16c70239
    t_disp_queue = 0xffffffff87c86d28
    t_disp_time = 0x16c7131a
    t_kpri_req = 0
    t_stkbase = 0xfffffe800015d000
    t_sleepq = sleepq_head+0x1270
    t_dtrace_regv = 0
    t_hrtime = 0x1dc821f2628013
}
```

Who's Creating Threads?

```
# dtrace -n 'thread_create:entry { @[execname]=count()}'
dtrace: description 'thread_create:entry ' matched 1 probe
^C

  sh                                                                1
  sched                                                             1
  do1.6499                                                          2
  do1.6494                                                          2
  do1.6497                                                          2
  do1.6508                                                          2
  in.rshd                                                          12
  do1.6498                                                         14
  do1.6505                                                         16
  do1.6495                                                         16
  do1.6504                                                         16
  do1.6502                                                         16
  automountd                                                       17
  inetd                                                            19
  filebench                                                        34
  find                                                            130
  csh                                                             177
```

Scheduling Classes & The Kernel Dispatcher

Solaris Scheduling

- Solaris implements a central dispatcher, with multiple scheduling classes
  - Scheduling classes determine the priority range of the kernel threads on the system-wide (global) scale, and the scheduling algorithms applied
  - Each scheduling class references a dispatch table
    - Values used to determine time quantums and priorities
    - Admin interface to “tune” thread scheduling
  - Solaris provides command line interfaces for
    - Loading new dispatch tables
    - Changing the scheduling class and priority and threads
  - Observability through
    - `ps`(1)
    - `prstat`(1)
    - `dtrace`(1)

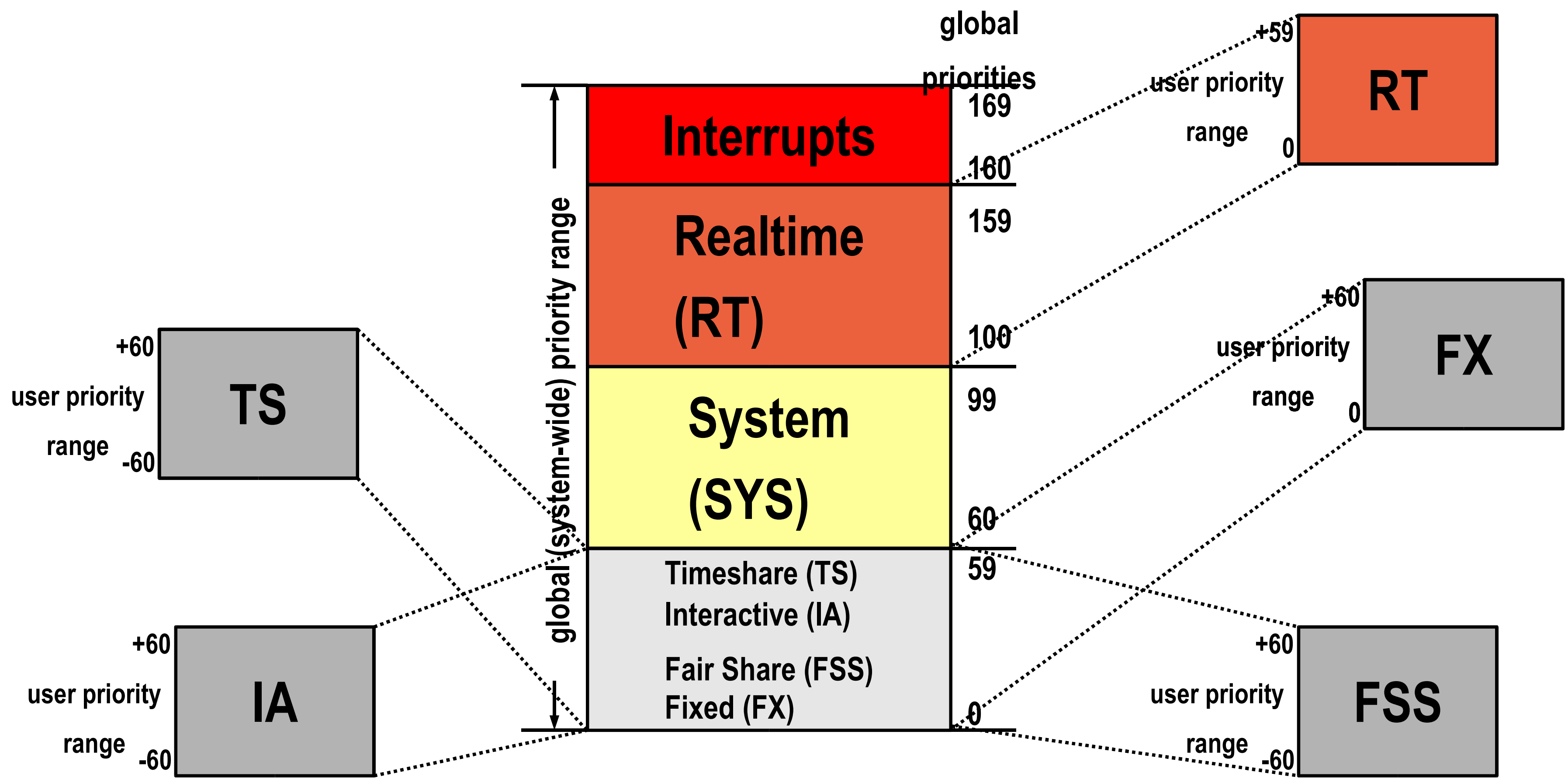
Scheduling Classes

- Traditional Timeshare (TS) class
  - > attempt to give every thread a fair shot at execution time
- Interactive (IA) class
  - > Desktop only
  - > Boost priority of active (current focus) window
  - > Same dispatch table as TS
- System (SYS)
  - > Only available to the kernel, for OS kernel threads
- Realtime (RT)
  - > Highest priority scheduling class
  - > Will preempt kernel (SYS) class threads
  - > Intended for realtime applications
    - > Bounded, consistent scheduling latency

Scheduling Classes – Solaris 9 & 10

- Fair Share Scheduler (FSS) Class
  - Same priority range as TS/IA class
  - CPU resources are divided into shares
  - Shares are allocated (projects/tasks) by administrator
  - Scheduling decisions made based on shares allocated and used, not dynamic priority changes
- Fixed Priority (FX) Class
  - The kernel will not change the thread's priority
  - A “batch” scheduling class
- Same set of commands for administration and management
  - `dispadmin`(1M), `priocntl`(1)
  - Resource management framework
    - `rctladm`(1M), `prctl`(1)

Scheduling Classes and Priorities



Scheduling Classes

- Use `dispadmin`(1M) and `priocntl`(1)

```
# dispadmin -l
CONFIGURED CLASSES
==================

SYS    (System Class)
TS     (Time Sharing)
FX     (Fixed Priority)
IA     (Interactive)
FSS    (Fair Share)
RT     (Real Time)
# priocntl -l
CONFIGURED CLASSES
==================

SYS (System Class)

TS (Time Sharing)
        Configured TS User Priority Range: -60 through 60

FX (Fixed priority)
        Configured FX User Priority Range: 0 through 60

IA (Interactive)
        Configured IA User Priority Range: -60 through 60

FSS (Fair Share)
        Configured FSS User Priority Range: -60 through 60

RT (Real Time)
        Maximum Configured RT Priority: 59
#
```

Scheduling Classes

- The kernel maintains an array of sclass structures for each loaded scheduling class
  - References the scheduling classes init routine, class functions structure, etc
- Scheduling class information is maintained for every kernel thread
  - Thread pointer to the class functions array, and per-thread class-specific data structure
  - Different threads in the same process can be in different scheduling classes
- Scheduling class operations vectors and CL_XXX macros allow a single, central dispatcher to invoke scheduling-class specific functions

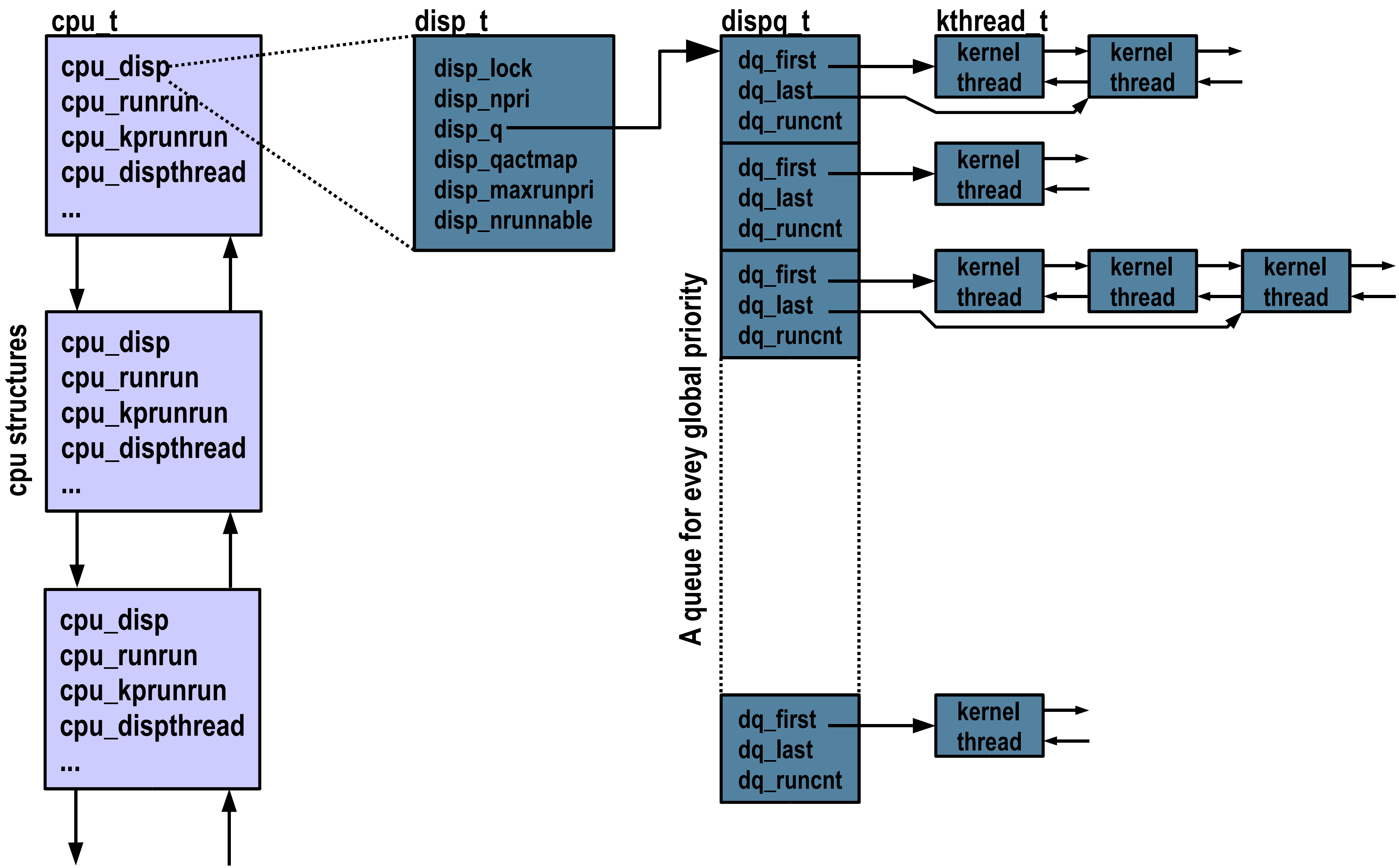
Scheduling Class & Priority of Threads

```
solaris10> ps -eLc
   PID   LWP  CLS PRI TTY        LTIME CMD
     0     1  SYS  96 ?           0:00 sched
     1     1   TS  59 ?           0:00 init
     2     1  SYS  98 ?           0:00 pageout
     3     1  SYS  60 ?           5:08 fsflush
   402     1   TS  59 ?           0:00 sac
   269     1   TS  59 ?           0:00 utmpd
   225     1   TS  59 ?           0:00 automoun
   225     2   TS  59 ?           0:00 automoun
   225     4   TS  59 ?           0:00 automoun
    54     1   TS  59 ?           0:00 sysevent
    54     2   TS  59 ?           0:00 sysevent
    54     3   TS  59 ?           0:00 sysevent
    [snip]
   426     1   IA  59 ?           0:00 dtgreet
   343     1   TS  59 ?           0:00 mountd
   345     1   FX  60 ?           0:00 nfsd
   345     3   FX  60 ?           0:00 nfsd
   350     1   TS  59 ?           0:00 dtlogin
   375     1   TS  59 ?           0:00 snmpdx
   411     1   IA  59 ?           0:00 dtlogin
   412     1   IA  59 ??          0:00 fbconsol
   403     1   TS  59 console     0:00 ttymon
   405     1   TS  59 ?           0:00 ttymon
   406     1   IA  59 ?           0:03 Xsun
   410     1   TS  59 ?           0:00 sshd
   409     1   TS  59 ?           0:00 snmpd
  1040     1   TS  59 ?           0:00 in.rlogi
  1059     1   TS  49 pts/2       0:00 ps
solaris10>
```

Dispatch Queues & Dispatch Tables

- Dispatch queues
  > Per-CPU run queues
    > Actually, a queue of queues
  > Ordered by thread priority
  > Queue occupation represented via a bitmap
  > For Realtime threads, a system-wide kernel preempt queue is maintained
    > Realtime threads are placed on this queue, not the per-CPU queues
    > If processor sets are configured, a kernel preempt queue exists for each processor set
- Dispatch tables
  > Per-scheduling class parameter tables
  > Time quantums and priorities
  > tuneable via `dispadmin`(1M)

Per-CPU Dispatch Queues



Timeshare Dispatch Table

- TS and IA class share the same dispatch table
  - *RES*. Defines the granularity of ts_quantum
  - *ts_quantum*. CPU time for next ONPROC state
  - *ts_tqexp*. New priority if time quantum expires
  - *ts_slpret*. New priority when state change from TS_SLEEP to TS_RUN
  - *ts_maxwait*. “waited too long” ticks
  - *ts_lwait.* New priority if “waited too long”

```
# dispadmin -g -c TS
# Time Sharing Dispatcher Configuration
RES=1000

# ts_quantum           ts_tqexp ts_slpret  ts_maxwait     ts_lwait          PRIORITY LEVEL
      200         0          50          0           50                #       0
      200         0          50          0           50                #       1
      .........
      160         0          51          0           51                #      10
      160         1          51          0           51                #      11
      ..........
      120         10         52          0           52                #      20
      120         11         52          0           52                #      21
      .........
      80          20         53          0           53                #      30
      80          21         53          0           53                #      31
      ..........
      40          30         55          0           55                #      40
      40          31         55          0           55                #      41
      ...........
      20          49         59          32000       59                #      59
```

RT, FX & FSS Dispatch Tables

- RT
  - Time quantum only
  - For each possible priority
- FX
  - Time quantum only
  - For each possible priority
- FSS
  - Time quantum only
  - Just one, not defined for each priority level
    - Because FSS is share based, not priority based
- SYS
  - No dispatch table
  - Not needed, no rules apply
- INT
  - Not really a scheduling class

Dispatch Queue Placement

- Queue placement is based a few simple parameters
  - The thread priority
  - Processor binding/Processor set
  - Processor thread last ran on
    - Warm affinity
  - Depth and priority of existing runnable threads
  - Solaris 9 added Memory Placement Optimization (MPO) enabled will keep thread in defined locality group (lgroup)

```
if (thread is bound to CPU-n) && (pri < kpreemptpri)
        CPU-n dispatch queue
if (thread is bound to CPU-n) && (pri >= kpreemptpri)
        CPU-n dispatch queue
if (thread is not bound) && (pri < kpreemptpri)
    place thread on a CPU dispatch queue
if (thread is not bound) && (pri >= kpreemptpri)
    place thread on cp_kp_queue
```

Thread Selection

- The kernel dispatcher implements a select-and-ratify thread selection algorithm
  - disp_getbest(). Go find the highest priority runnable thread, and select it for execution
  - disp_ratify(). Commit to the selection. Clear the CPU preempt flags, and make sure another thread of higher priority did not become runnable
    - If one did, place selected thread back on a queue, and try again
- Warm affinity is implemented
  - Put the thread back on the same CPU it executed on last
    - Try to get a warm cache
  - `rechoose_interval` kernel parameter
    - Default is 3 clock ticks

Thread Preemption

- Two classes of preemption
  - > User preemption
    - > A higher priority thread became runnable, but it's not a realtime thread
    - > Flagged via cpu_runrun in CPU structure
    - > Next clock tick, you're outta here
  - > Kernel preemption
    - > A realtime thread became runnable. Even OS kernel threads will get preempted
    - > Poke the CPU (cross-call) and preempt the running thread now
  - > Note that threads that use-up their time quantum are evicted via the preempt mechanism
  - > Monitor via “icsw” column in `mpstat`(1)

Thread Execution

- Run until
  - A preemption occurs
    - Transition from S_ONPROC to S_RUN
    - placed back on a run queue
  - A blocking system call is issued
    - e.g. read(2)
    - Transition from S_ONPROC to S_SLEEP
    - Placed on a sleep queue
  - Done and exit
    - Clean up
  - Interrupt to the CPU you're running on
    - pinned for interrupt thread to run
    - unpinned to continue

Context Switching

CPU	minf	mjf	xcal	intr	ithr	csw	icsw	migr	smtx	srw	syscl	usr	sys	wt	idl
0	74	2	998	417	302	450	18	45	114	0	1501	56	7	0	37
1	125	3	797	120	102	1107	16	58	494	0	1631	41	16	0	44
4	209	2	253	114	100	489	12	45	90	0	1877	56	11	0	33
5	503	7	2448	122	100	913	21	53	225	0	2626	32	21	0	48
8	287	3	60	120	100	771	20	35	122	0	1569	50	12	0	38
9	46	1	51	115	99	671	16	20	787	0	846	81	16	0	3
12	127	2	177	117	101	674	14	27	481	0	881	74	12	0	14
13	375	7	658	1325	1302	671	23	49	289	0	1869	48	16	0	37

CPU	minf	mjf	xcal	intr	ithr	csw	icsw	migr	smtx	srw	syscl	usr	sys	wt	idl
0	0	0	733	399	297	548	10	8	653	0	518	80	11	0	9
1	182	4	45	117	100	412	16	34	49	0	904	54	8	0	38
4	156	4	179	108	102	1029	6	46	223	0	1860	15	16	0	70
5	98	1	53	110	100	568	9	19	338	0	741	60	9	0	31
8	47	1	96	111	101	630	6	22	712	0	615	56	13	0	31
9	143	4	127	116	102	1144	11	42	439	0	2443	33	15	0	52
12	318	0	268	111	100	734	9	30	96	0	1455	19	12	0	69
13	39	2	16	938	929	374	8	9	103	0	756	69	6	0	25

```
#!/usr/sbin/dtrace -Zqs
long inv_cnt;    /* all invountary context switches */
long tqe_cnt;    /* time quantum expiration count   */
long hpp_cnt;    /* higher-priority preempt count   */
long csw_cnt;    /* total number context switches   */

dtrace:::BEGIN
{
        inv_cnt = 0; tqe_cnt = 0; hpp_cnt = 0; csw_cnt = 0;

        printf("%-16s %-16s %-16s %-16s\n","TOTAL CSW","ALL INV","TQE_INV","HPP_INV");
        printf("==========================================================\n");
}

sysinfo:unix:preempt:inv_swtch
{
        inv_cnt += arg0;
}
sysinfo:unix::pswitch
{
        csw_cnt += arg0;
}

fbt:TS:ts_preempt:entry
/ ((tsproc_t *)args[0]->t_cldata)->ts_timeleft <= 1 /
{
        tqe_cnt++;
}

fbt:TS:ts_preempt:entry
/ ((tsproc_t *)args[0]->t_cldata)->ts_timeleft > 1 /
{
        hpp_cnt++;
}

fbt:RT:rt_preempt:entry
/ ((rtproc_t *)args[0]->t_cldata)->rt_timeleft <= 1 /
{
        tqe_cnt++;
}
fbt:RT:rt_preempt:entry
/ ((rtproc_t *)args[0]->t_cldata)->rt_timeleft > 1 /
{
        hpp_cnt++;
}
tick-1sec
{
        printf("%-16d %-16d %-16d %-16d\n",csw_cnt,inv_cnt,tqe_cnt,hpp_cnt);

        inv_cnt = 0; tqe_cnt = 0; hpp_cnt = 0; csw_cnt = 0;
}
```

```
solaris10> ./csw.d
TOTAL CSW         ALL INV           TQE_INV           HPP_INV
==========================================================
1544              63                24                40
3667              49                35                14
4163              59                34                26
3760              55                29                26
3839              71                39                32
3931              48                33                15
^C

solaris10> ./threads &
[2]     19913
solaris10>
solaris10> ./csw.d
TOTAL CSW         ALL INV           TQE_INV           HPP_INV
==========================================================
3985              1271              125               1149
5681              1842              199               1648
5025              1227              151               1080
9170              520               108               412
4100              390               84                307
2487              174               74                99
1841              113               64                50
6239              170               74                96
^C
1440              155               68                88
```

Sleep & Wakeup

- Condition variables used to synchronize thread sleep/wakeup
  - A block condition (waiting for a resource or an event) enters the kernel cv_xxx() functions
  - The condition variable is set, and the thread is placed on a sleep queue
  - Wakeup may be directed to a specific thread, or all threads waiting on the same event or resource
    - One or more threads moved from sleep queue, to run queue

Observability and Performance

- Use `prstat`(1) and `ps`(1) to monitor running processes and threads
- Use `mpstat`(1) to monitor CPU utilization, context switch rates and thread migrations
- Use `dispadmin`(1M) to examine and change dispatch table parameters
- User `priocntl`(1) to change scheduling classes and priorities
  - `nice`(1) is obsolete (but there for compatibility)
  - User priorities also set via `priocntl`(1)
  - Must be root to use RT class

Dtrace sched provider probes:

- change-pri – change pri
- dequeue – exit run q
- enqueue – enter run q
- off-cpu – start running
- on-cpu – stop running
- preempt - preempted
- remain-cpu
- schedctl-nopreempt – hint that it is not ok to preempt
- schedctl-preempt – hint that it is ok to preempt
- schedctl-yield - hint to give up runnable state
- sleep – go to sleep
- surrender – preempt from another cpu
- tick – tick-based accounting
- wakeup – wakeup from sleep

Turnstiles & Priority Inheritance

- Turnstiles are a specific implementation of sleep queues that provide priority inheritance
- Priority Inheritance (PI) addresses the *priority inversion problem*
  - > Priority inversion is when a higher priority thread is prevented from running because a lower priority thread is holding a lock the higher priority thread needs
    - > Blocking chains can form when “mid” priority threads get in the mix
- Priority inheritance
  - > If a resource is held, ensure all the threads in the blocking chain are at the requesting thread's priority, or better
    - > All lower priority threads inherit the priority of the requestor

Processors, Processor Controls & Binding

Processor Controls

- Processor controls provide for segregation of workload(s) and resources
- Processor status, state, management and control
  - Kernel linked list of CPU structs, one for each CPU
  - Bundled utilities
    - `psradm`(1)
    - `psrinfo`(1)
  - Processors can be taken offline
    - Kernel will not schedule threads on an offline CPU
  - The kernel can be instructed not to bind device interrupts to processor(s)
    - Or move them if bindings exist

Processor Control Commands

- `psrinfo`(1M) - provides information about the processors on the system. Use "-v" for verbose
- `psradm`(1M) - online/offline processors. Pre Sol 7, offline processors still handled interrupts. In Sol 7, you can disable interrupt participation as well
- `psrset`(1M) - creation and management of processor sets
- `pbind`(1M) - original processor bind command. Does not provide exclusive binding
- `processor_bind`(2), `processor_info`(2), `pset_bind`(2), `pset_info`(2), `pset_creat`(2), `p_online`(2)
  - system calls to do things programmatically

Processor Sets

- Partition CPU resources for segregating workloads, applications and/or interrupt handling
- Dynamic
  > Create, bind, add, remove, etc, without reboots
- Once a set is created, the kernel will only schedule threads onto the set that have been explicitly bound to the set
  > And those threads will only ever be scheduled on CPUs in the set they've been bound to
- Interrupt disabling can be done on a set
  > Dedicate the set, through binding, to running application threads
  > Interrupt segregation can be effective if interrupt load is heavy
    > e.g. high network traffic

Example: Managing a cpuhog

Timeshare (TS) Scheduling (prstat -l)

```
   PID USERNAME  SIZE   RSS STATE  PRI NICE      TIME  CPU PROCESS/LWPID
   746 mauroj    118M  118M sleep   59    0   0:00:20 3.5% cpuhog/6
   746 mauroj    118M  118M sleep   59    0   0:00:19 3.3% cpuhog/5
   746 mauroj    118M  118M sleep   33    0   0:00:19 3.2% cpuhog/22
   746 mauroj    118M  118M sleep   59    0   0:00:20 3.2% cpuhog/30
   746 mauroj    118M  118M sleep   40    0   0:00:20 3.1% cpuhog/23
   746 mauroj    118M  118M sleep   59    0   0:00:19 3.1% cpuhog/31
   746 mauroj    118M  118M sleep   59    0   0:00:18 3.0% cpuhog/26
   746 mauroj    118M  118M sleep   59    0   0:00:19 3.0% cpuhog/17
   746 mauroj    118M  118M sleep   59    0   0:00:20 2.9% cpuhog/8
   746 mauroj    118M  118M cpu8    20    0   0:00:18 2.9% cpuhog/9
   746 mauroj    118M  118M sleep   51    0   0:00:18 2.9% cpuhog/10
   746 mauroj    118M  118M sleep   51    0   0:00:20 2.9% cpuhog/2
   746 mauroj    118M  118M cpu13   42    0   0:00:19 2.9% cpuhog/15
   746 mauroj    118M  118M sleep   59    0   0:00:17 2.8% cpuhog/20
   746 mauroj    118M  118M sleep   59    0   0:00:19 2.8% cpuhog/32
   746 mauroj    118M  118M sleep   59    0   0:00:18 2.8% cpuhog/18
   746 mauroj    118M  118M sleep   59    0   0:00:17 2.7% cpuhog/27
   746 mauroj    118M  118M sleep   59    0   0:00:17 2.7% cpuhog/21
   746 mauroj    118M  118M sleep   33    0   0:00:17 2.7% cpuhog/12
   746 mauroj    118M  118M sleep   59    0   0:00:17 2.7% cpuhog/16
   746 mauroj    118M  118M sleep   42    0   0:00:17 2.7% cpuhog/3
   746 mauroj    118M  118M sleep   31    0   0:00:17 2.7% cpuhog/13
   746 mauroj    118M  118M sleep   55    0   0:00:19 2.7% cpuhog/7
   746 mauroj    118M  118M sleep   33    0   0:00:18 2.5% cpuhog/4
   746 mauroj    118M  118M sleep   59    0   0:00:18 2.4% cpuhog/24
   746 mauroj    118M  118M cpu4    39    0   0:00:16 2.3% cpuhog/14
   746 mauroj    118M  118M sleep   43    0   0:00:15 2.3% cpuhog/11
   746 mauroj    118M  118M cpu0    59    0   0:00:17 2.3% cpuhog/33
   746 mauroj    118M  118M sleep   31    0   0:00:15 2.2% cpuhog/19
   746 mauroj    118M  118M sleep   59    0   0:00:15 2.2% cpuhog/29
   746 mauroj    118M  118M sleep   30    0   0:00:15 2.1% cpuhog/25
   746 mauroj    118M  118M sleep   59    0   0:00:15 2.0% cpuhog/28
   747 mauroj   4704K 4408K cpu5    49    0   0:00:00 0.0% prstat/1
```

Timeshare – No partitioning

CPU	minf	mjf	xcal	intr	ithr	csw	icsw	migr	smtx	srw	syscl	usr	sys	wt	idl
0	18	0	777	412	303	88	38	24	43	0	173	73	0	0	27
1	30	0	13	124	101	86	34	16	44	0	181	91	0	0	9
4	22	0	4	131	112	69	31	15	37	0	84	98	0	0	2
5	26	0	7	116	100	59	26	10	44	0	76	99	1	0	0
8	24	0	6	121	100	64	33	16	33	0	105	96	2	0	2
9	22	0	5	116	100	63	27	11	39	0	73	96	2	0	2
12	20	0	4	119	101	76	26	18	29	0	70	86	0	0	14
13	20	0	13	115	100	72	26	14	40	0	80	84	2	0	14
CPU	minf	mjf	xcal	intr	ithr	csw	icsw	migr	smtx	srw	syscl	usr	sys	wt	idl
0	26	0	761	407	301	45	28	14	43	0	80	87	0	0	13
1	18	0	5	116	101	86	27	23	35	1	73	89	0	0	11
4	24	0	7	124	110	64	29	12	30	0	60	99	1	0	0
5	14	0	22	115	101	82	30	23	45	0	97	71	2	0	27
8	28	0	7	113	100	61	24	11	42	0	69	94	4	0	2
9	24	0	5	116	101	75	25	22	41	0	83	78	5	0	17
12	34	0	8	119	101	71	28	18	29	0	63	90	8	0	2
13	20	0	8	122	100	74	33	17	33	0	71	76	5	0	19

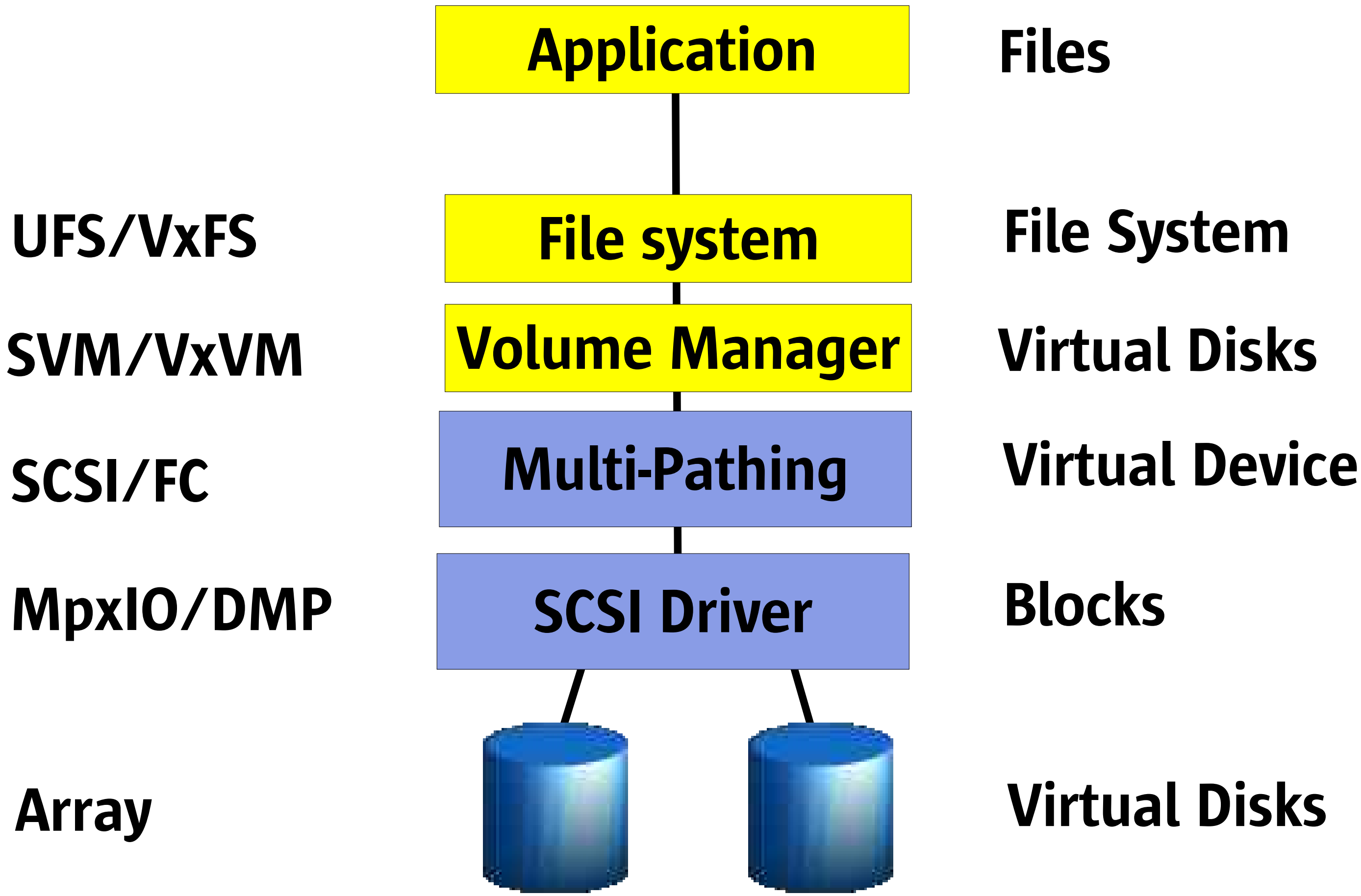
Creating a Processor Set for cpuhog

```
# psrinfo
0    on-line   since 09/19/2003 01:18:13
1    on-line   since 09/19/2003 01:18:17
4    on-line   since 09/19/2003 01:18:17
5    on-line   since 09/19/2003 01:18:17
8    on-line   since 09/19/2003 01:18:17
9    on-line   since 09/19/2003 01:18:17
12   on-line   since 09/19/2003 01:18:17
13   on-line   since 09/19/2003 01:18:17
# psrset -c 8 9 12 13
created processor set 1
processor 8: was not assigned, now 1
processor 9: was not assigned, now 1
processor 12: was not assigned, now 1
processor 13: was not assigned, now 1
# psrset -e 1 ./cpuhog 1 0
```

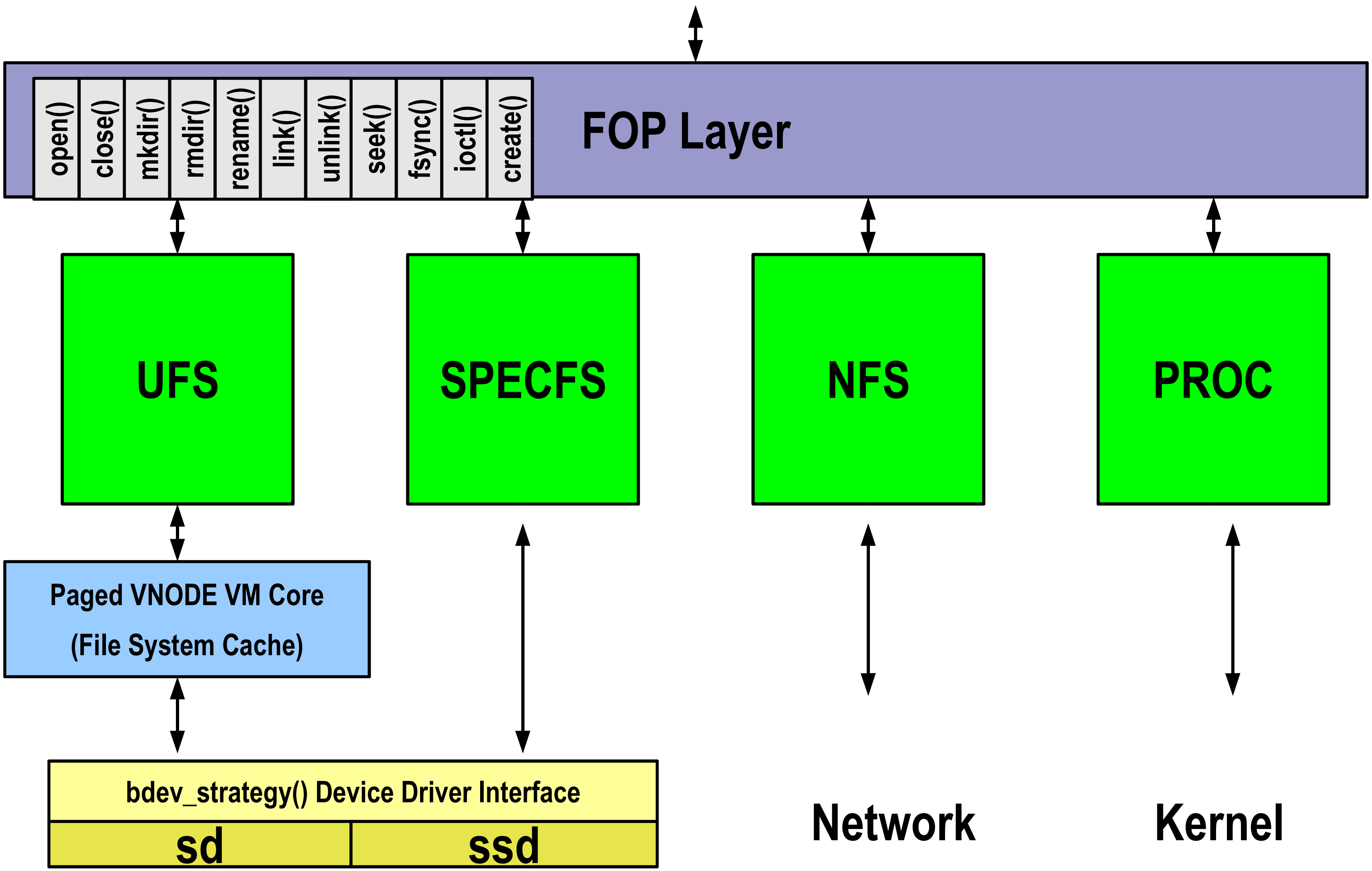
```
# mpstat 1
CPU minf mjf xcal  intr ithr  csw icsw migr smtx  srw syscl  usr sys  wt idl
  0    0   0  746   401  301   12    0    1   10    0     0    0   0   0 100
  1    0   0    0   101  100   12    0    0    0    0    27    0   0   0 100
  4    0   0    5   109  107   14    0    0    0    0     0    0   0   0 100
  5    0   0    0   103  102   10    0    0    0    0     0    0   0   0 100
  8   71   0    9   124  100   81   42    6   51    0   101  100   0   0   0
  9   66   0   13   121  100   84   39    3   48    0   111   99   1   0   0
 12   49   0    5   117  100   71   27    6   29    0    88   99   1   0   0
 13   55   0    4   124  100   76   40    6   35    0    90  100   0   0   0
```

Session 4
File Systems &
Disk I/O Performance

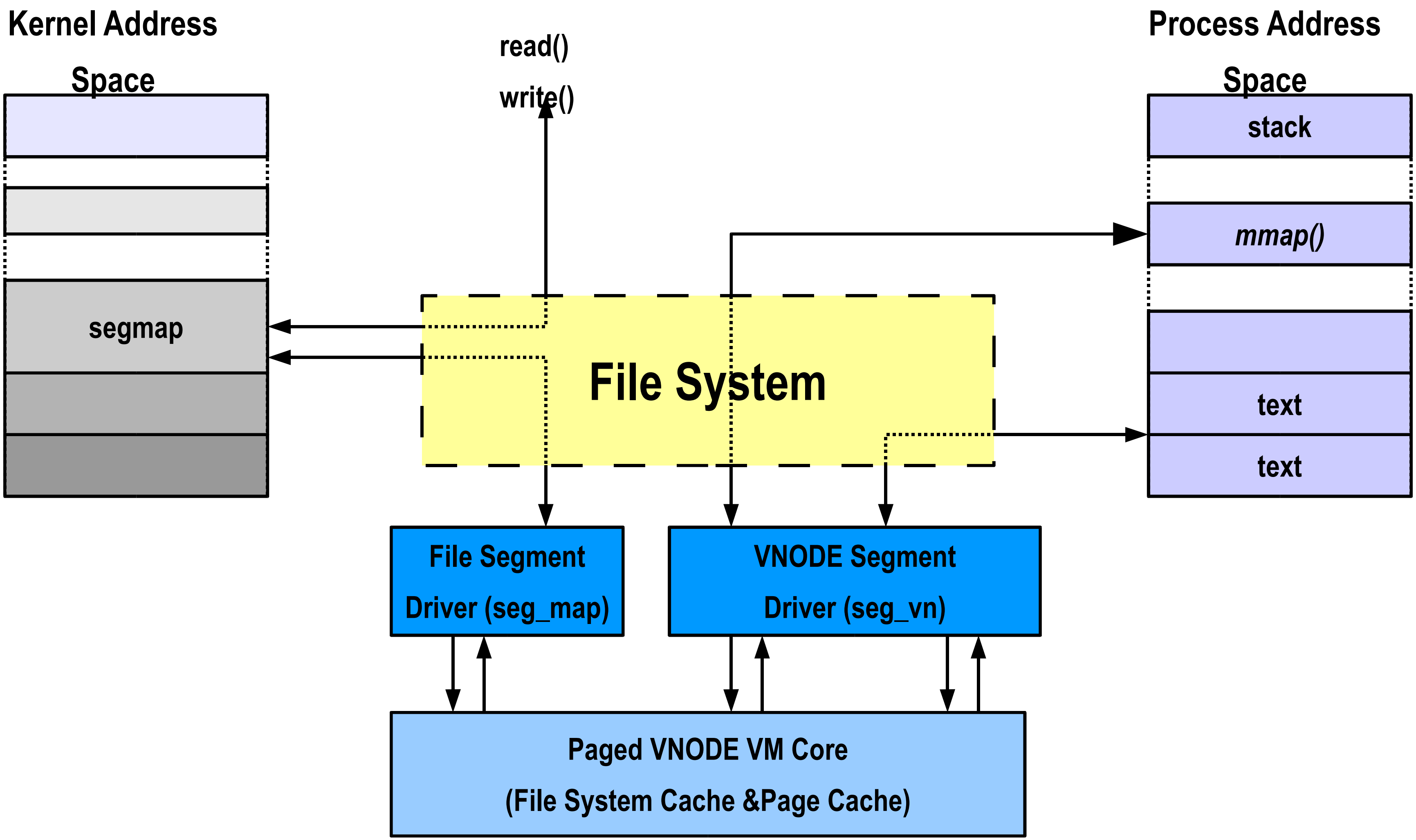
The Solaris File System/IO Stack



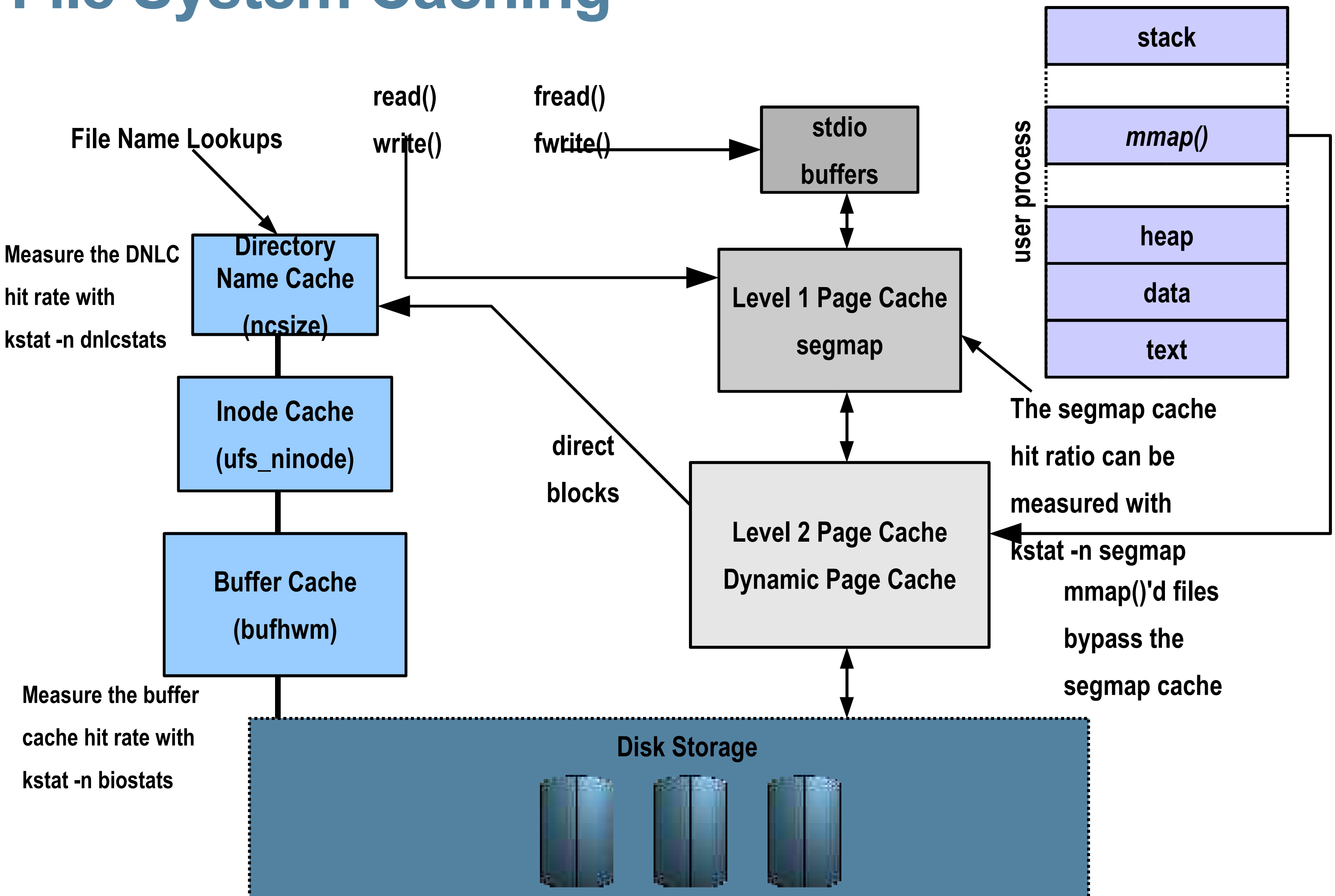
File System Architecture



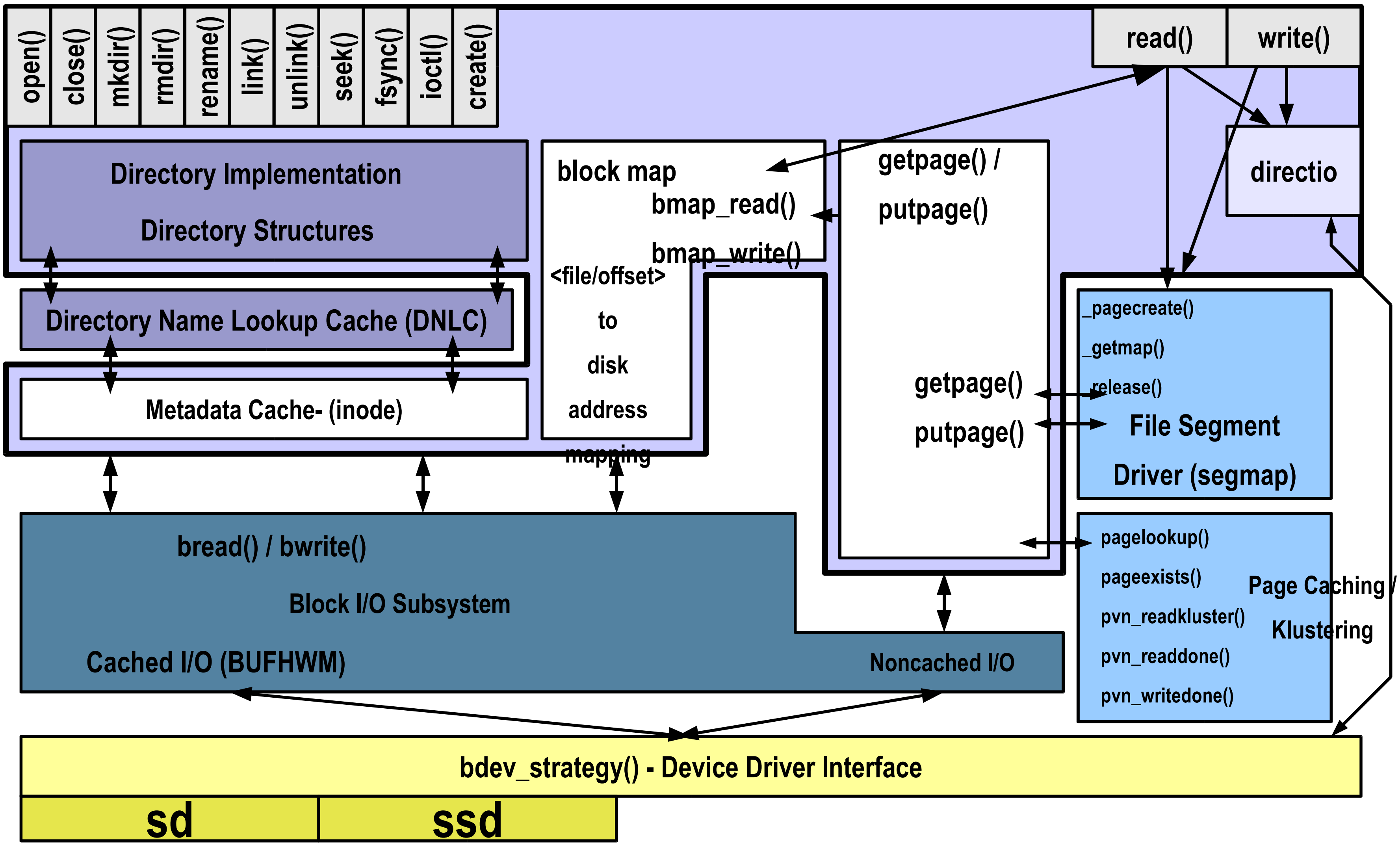
File System I/O



File System Caching



Disk-based File System Architecture



Filesystem performance

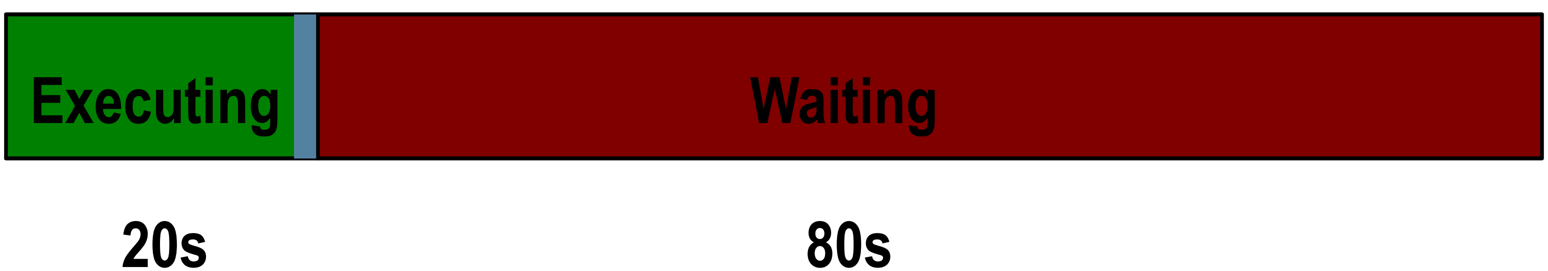
- Attribution
  > How much is my application being slowed by I/O?
  > i.e. How much faster would my app run if I optimized I/O?
- Accountability
  > What is causing I/O device utilization?
  > i.e. What user is causing this disk to be hot?
- Tuning/Optimizing
  > Tuning for sequential, random I/O and/or meta-data intensive applications

Solaris FS Perf Tools

- iostat: raw disk statistics
- sar -b: meta-data buffer cachestat
- vmstat -s: monitor dnlc
- Filebench: emulate and measure various FS workloads
- DTrace: trace physical I/O
- DTrace: top for files – logical and physical per file
- DTrace: top for fs – logical and physical per filesystem

Simple performance model

- Single-threaded processes are simpler to estimate
  - Calculate elapsed vs. waiting for I/O time, express as a percentage
  - i.e. My app spent 80% of its execution time waiting for I/O
  - Inverse is potential speed up – e.g. 80% of time waiting equates to a potential 5x speedup



- The key is to estimate the time spent waiting

Estimating wait time

- Elapsed vs. cpu seconds
  - Time <cmd>, estimate wait as real – user - sys
- Etruss
  - Uses microstates to estimate I/O as wait time
  - http://www.solarisinternals.com
- Measure explicitly with dtrace
  - Measure and total I/O wait per thread

Examining IO wait with dtrace

- Measuring on-cpu vs io-wait time:

```
sol10$ ./iowait.d 639
^C
Time breakdown (milliseconds):
 <on cpu>                                                     2478
 <I/O wait>                                                   6326

I/O wait breakdown (milliseconds):
 file1                                                         236
 file2                                                         241
 file4                                                         244
 file3                                                         264
 file5                                                         277
 file7                                                         330
 .
 .
 .
```

Solaris iostat

```
# iostat -xnz
                    extended device statistics
    r/s    w/s   kr/s   kw/s wait actv wsvc_t asvc_t  %w  %b device
  687.8    0.0 38015.3    0.0  0.0  1.9    0.0    2.7   0 100 c0d0
```

- Wait: number of threads queued for I/O
- Actv: number of threads performing I/O
- wsvc_t: Average time spend waiting on queue
- asvc_t: Average time performing I/O
- %w: Only useful if one thread is running on the entire machine – time spent waiting for I/O
- %b: Device utilization – only useful if device can do just 1 I/O at a time (invalid for arrays etc...)

Thread I/O example

```
sol8$ cd labs/disks
sol8$ ./1thread
 1079: 0.007: Random Read Version 1.8 05/02/17 IO personality successfully loaded
 1079: 0.008: Creating/pre-allocating files
 1079: 0.238: Waiting for preallocation threads to complete...
 1079: 0.238: Re-using file /filebench/bigfile0
 1079: 0.347: Starting 1 rand-read instances
 1080: 1.353: Starting 1 rand-thread threads
 1079: 4.363: Running for 600 seconds...
sol8$ iostat -xncz 5
      cpu
 us sy wt id
 22  3  0 75
                    extended device statistics
    r/s    w/s   kr/s   kw/s wait actv wsvc_t asvc_t  %w  %b device
   62.7    0.3  501.4    2.7  0.0  0.9    0.0   14.1   0  89 c1d0
```

64 Thread I/O example

```
sol8$ cd labs/disks
sol8$ ./64thread
 1089: 0.095: Random Read Version 1.8 05/02/17 IO personality successfully loaded
 1089: 0.096: Creating/pre-allocating files
 1089: 0.279: Waiting for preallocation threads to complete...
 1089: 0.279: Re-using file /filebench/bigfile0
 1089: 0.385: Starting 1 rand-read instances
 1090: 1.389: Starting 64 rand-thread threads
 1089: 4.399: Running for 600 seconds...

sol8$ iostat -xncz 5
      cpu
 us sy wt id
 15  1  0 83
                   extended device statistics
    r/s    w/s   kr/s   kw/s wait actv wsvc_t asvc_t  %w  %b device
   71.0    0.3  568.0   17.3 61.8  2.0  866.5   28.0 100 100 c1d0
```

Solaris iostat: New opts. since Solaris 8

- New Formatting flags -C, -l, -m, -r, -s, -z, -T
  - -C: report disk statistics by controller
  - -l n: Limit the number of disks to n
  - -m: Display mount points (most useful with -p)
  - -r: Display data n comma separated format
  - -s: Suppress state change messages
  - -z: Suppress entries with all zero values
  - -T d|u Display a timestamp in date (d) or unix time_t (u)

Examining Physical IO by file with dtrace

```
#pragma D option quiet

BEGIN
{
        printf("%10s %58s %2s %8s\n", "DEVICE", "FILE", "RW", "Size");
}

io:::start
{
        printf("%10s %58s %2s %8d\n", args[1]->dev_statname,
            args[2]->fi_pathname, args[0]->b_flags & B_READ ? "R" : "W",
            args[0]->b_bcount);
}

# dtrace -s ./iotrace

    DEVICE                                                       FILE RW     SIZE
     cmdk0                                  /export/home/rmc/.sh_history  W     4096
     cmdk0                                    /opt/Acrobat4/bin/acroread  R     8192
     cmdk0                                    /opt/Acrobat4/bin/acroread  R     1024
     cmdk0                                    /var/tmp/wscon-:0.0-gLaW9a  W     3072
     cmdk0                              /opt/Acrobat4/Reader/AcroVersion  R     1024
     cmdk0                 /opt/Acrobat4/Reader/intelsolaris/bin/acroread  R     8192
     cmdk0                 /opt/Acrobat4/Reader/intelsolaris/bin/acroread  R     8192
     cmdk0                 /opt/Acrobat4/Reader/intelsolaris/bin/acroread  R     4096
     cmdk0                 /opt/Acrobat4/Reader/intelsolaris/bin/acroread  R     8192
     cmdk0                 /opt/Acrobat4/Reader/intelsolaris/bin/acroread  R     8192
```

Physical Trace Example

```
sol8$ cd labs/disks
sol8$ ./64thread
 1089: 0.095: Random Read Version 1.8 05/02/17 IO personality successfully loaded
 1089: 0.096: Creating/pre-allocating files
 1089: 0.279: Waiting for preallocation threads to complete...
 1089: 0.279: Re-using file /filebench/bigfile0
 1089: 0.385: Starting 1 rand-read instances
 1090: 1.389: Starting 64 rand-thread threads
 1089: 4.399: Running for 600 seconds...

sol8$ iotrace.d
    DEVICE                                           FILE RW      Size
     cmdk0                           /filebench/bigfile0  R      8192
     cmdk0                           /filebench/bigfile0  R      8192
     cmdk0                           /filebench/bigfile0  R      8192
     cmdk0                           /filebench/bigfile0  R      8192
     cmdk0                           /filebench/bigfile0  R      8192
     cmdk0                           /filebench/bigfile0  R      8192
     cmdk0                           /filebench/bigfile0  R      8192
     cmdk0                           /filebench/bigfile0  R      8192
     cmdk0                           /filebench/bigfile0  R      8192
     cmdk0                           /filebench/bigfile0  R      8192
     cmdk0                           /filebench/bigfile0  R      8192
```

Using Dtrace to examine File System Performance

File system I/O via Virtual Memory

- File system I/O is performed by the VM system
  - > Reads are performed by page-in
  - > Write are performed by page-out
- Practical Implications
  - > Virtual memory caches files, cache is dynamic
  - > Minimum I/O size is the page size
  - > Read/modify/write may occur on sub page-size writes
- Memory Allocation Policy:
  - > File system cache is lower priority than app, kernel etc
  - > File system cache grows when there is free memory available
  - > File system cache shrinks when there is demand elsewhere.

File System Reads: A UFS Read

- Application calls read()
- Read system call calls fop_read()
- FOP layer redirector calls underlying filesystem
- FOP jumps into ufs_read
- UFS locates a mapping for the corresponding pages in the file system page cache using vnode/offset
- UFS asks segmap for a mapping to the pages
- If the page exists in the fs, data is copied to App.
  - We're done.
- If the page doesn't exist, a Major fault occurs
  - VM system invokes ufs_getpage()
  - UFS schedules a page size I/O for the page
  - When I/O is complete, data is copied to App.

vmstat -p

swap = free and unreserved swap in KBytes

free = free memory measured in pages

re = kilobytes reclaimed from cache/free list

mf = minor faults - the page was in memory but was not mapped

fr = kilobytes that have been destroyed or freed

de = kilobytes freed after writes

sr = kilobytes scanned / second

executable pages: kilobytes in - out - freed

anonymous pages: kilobytes in - out – freed

file system pages:

kilobytes in - out - freed

```
# vmstat -p 5 5
      memory                page             executable       anonymous        filesystem
   swap    free     re  mf  fr   de   sr   epi   epo   epf   api   apo   apf   fpi   fpo   fpf
 ...
 46715224 891296 24  350 0    0    0     0     0     0     4     0     0    27     0     0
 46304792 897312 151 761 25   0    0    17     0     0     1     0     0   280    25    25
 45886168 899808 118 339 1    0    0     3     0     0     1     0     0   641     1     1
 46723376 899440 29  197 0    0    0     0     0     0    40     0     0    60     0     0
```

Observing the File System I/O Path

```
Sol10# cd labs/fs_paging
sol10# ./fsread
 2055: 0.004: Random Read Version 1.8 05/02/17 IO personality successfully loaded
 2055: 0.004: Creating/pre-allocating files
 2055: 0.008: Waiting for preallocation threads to complete...
 2055: 28.949: Pre-allocated file /filebench/bigfile0
 2055: 30.417: Starting 1 rand-read instances
 2056: 31.425: Starting 1 rand-thread threads
 2055: 34.435: Running for 600 seconds...

sol10# vmstat -p 3
     memory           page          executable      anonymous      filesystem
   swap  free  re  mf  fr  de  sr  epi  epo  epf  api  apo  apf  fpi  fpo  fpf
 1057528 523080 22 105  0   0   8    5    0    0    0    0    0   63    0    0
 776904 197472  0  12   0   0   0    0    0    0    0    0    0  559    0    0
 776904 195752  0   0   0   0   0    0    0    0    0    0    0  555    0    0
 776904 194100  0   0   0   0   0    0    0    0    0    0    0  573    0    0

sol10# ./pagingflow.d
  0  => pread64                                                  0
  0    | pageio_setup:pgin                                      40
  0    | pageio_setup:pgpgin                                    42
  0    | pageio_setup:maj_fault                                 43
  0    | pageio_setup:fspgin                                    45
  0    | bdev_strategy:start                                    52
  0    | biodone:done                                        11599
  0  <= pread64                                              11626
```

Observing File System I/O

```
Sol10# cd labs/fs_paging
sol10# ./fsread
 2055: 0.004: Random Read Version 1.8 05/02/17 IO personality successfully loaded
 2055: 0.004: Creating/pre-allocating files
 2055: 0.008: Waiting for preallocation threads to complete...
 2055: 28.949: Pre-allocated file /filebench/bigfile0
 2055: 30.417: Starting 1 rand-read instances
 2056: 31.425: Starting 1 rand-thread threads
 2055: 34.435: Running for 600 seconds...

sol10# ./fspaging.d
Event          Device                                                   Path RW      Size
get-page                                                  /filebench/bigfile0        8192
getpage-io      cmdk0                                     /filebench/bigfile0  R     8192
get-page                                                  /filebench/bigfile0        8192
getpage-io      cmdk0                                     /filebench/bigfile0  R     8192
get-page                                                  /filebench/bigfile0        8192
getpage-io      cmdk0                                     /filebench/bigfile0  R     8192
get-page                                                  /filebench/bigfile0        8192
```

Observing File System I/O: Sync Writes

```
Sol10# cd labs/fs_paging
sol10# ./fswritesync
 2276: 0.008: Random Write Version 1.8 05/02/17 IO personality successfully loaded
 2276: 0.009: Creating/pre-allocating files
 2276: 0.464: Waiting for preallocation threads to complete...
 2276: 0.464: Re-using file /filebench/bigfile0
 2276: 0.738: Starting 1 rand-write instances
 2277: 1.742: Starting 1 rand-thread threads
 2276: 4.743: Running for 600 seconds...

sol10# ./fspaging.d
Event            Device                                              Path RW      Size   Offset
put-page                                              /filebench/bigfile0         8192
putpage-io        cmdk0                               /filebench/bigfile0  W      8192 18702224
other-io          cmdk0                                            <none>  W       512    69219
put-page                                              /filebench/bigfile0         8192
putpage-io        cmdk0                               /filebench/bigfile0  W      8192 11562912
other-io          cmdk0                                            <none>  W       512    69220
put-page                                              /filebench/bigfile0         8192
putpage-io        cmdk0                               /filebench/bigfile0  W      8192 10847040
other-io          cmdk0                                            <none>  W       512    69221
put-page                                              /filebench/bigfile0         8192
putpage-io        cmdk0                               /filebench/bigfile0  W      8192 22170752
other-io          cmdk0                                            <none>  W       512    69222
put-page                                              /filebench/bigfile0         8192
putpage-io        cmdk0                               /filebench/bigfile0  W      8192 25189616
other-io          cmdk0                                            <none>  W       512    69223
put-page                                              /filebench/bigfile0         8192
```

Memory Mapped I/O

- Application maps file into process with mmap()
- Application references memory mapping
- If the page exists in the cache, we're done.
- If the page doesn't exist, a Major fault occurs
  - > VM system invokes ufs_getpage()
  - > UFS schedules a page size I/O for the page
  - > When I/O is complete, data is copied to App.

The big caches:

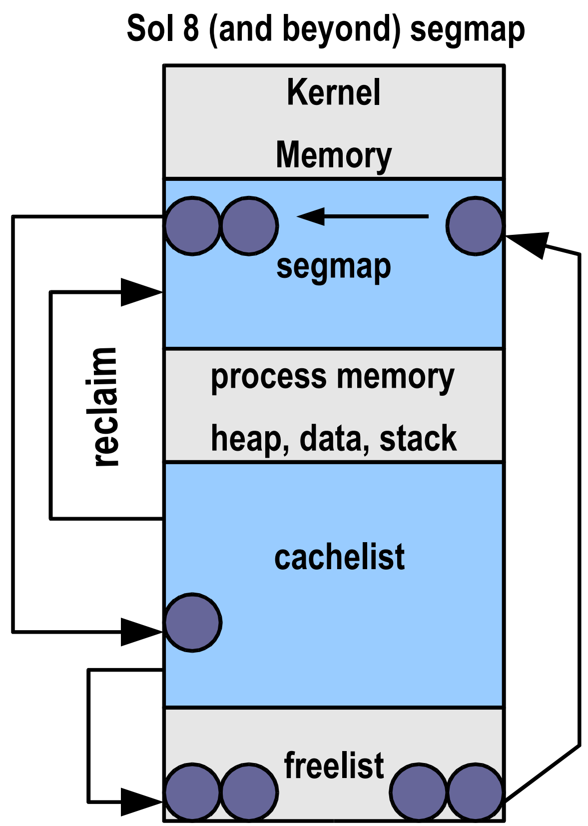
- File system/page cache
  - > Holds the “data” of the files
- Buffer Cache
  - > Holds the meta-data of the file system: direct/indirect blocks, inodes etc...
- Directory Name Cache
  - > Caches mappings of filename->vnode from recent lookups
  - > Prevents excessive re-reading of directory from disk
- File system specific: Inode cache
  - > Caches inode meta-data in memory
  - > Holds owner, mtimes etc

Optimizing Random I/O File System Performance

Random I/O

- Attempt to cache as much as possible
  - > The best I/O is the one you don't have to do
  - > Eliminate physical I/O
  - > Add more RAM to expand caches
  - > Cache at the highest level
    - > Cache in app if we can
    - > In Oracle if possible
- Match common I/O size to FS block size
  - > e.g. Write 2k on 8k FS = Read 8k, Write 8k

The Solaris File System Cache



Tuning segmap

- By default, segmap is sized at 12% of physical memory
  > Effectively sets the minimum amount of file system cache on the system by caching in segmap over and above the dynamically-sized cachelist
- On Solaris 8/9/10
  > If the system memory is used primarily as a cache, cross calls (mpstat xcall) can be reduced by increasing the size of segmap via the system parameter segmap_percent (12 by default)

  > segmap_percent = 100 is like Solaris 7 without priority paging, and will cause a paging storm

  > Must keep segmap_percent at a reasonable value to prevent paging pressure on applications e.g. 50%

Tuning segmap_percent

- There are kstat statistics for segmap hit rates
  - > Estimate hit rate as (get_reclaim+get_use) / getmap

```
# kstat -n segmap
module: unix                            instance: 0
name:   segmap                          class:    vm

        crtime                          17.299814595
        fault                           17361
        faulta                          0
        free                            0
        free_dirty                      0
        free_notfree                    0
        get_nofree                      0
        get_reclaim                     67404
        get_reuse                       0
        get_unused                      0
        get_use                         83
        getmap                          71177
        pagecreate                      757
        rel_abort                       0
        rel_async                       3073
        rel_dontneed                    3072
        rel_free                        616
        rel_write                       2904
        release                         67658
        snaptime                        583596.778903492
```

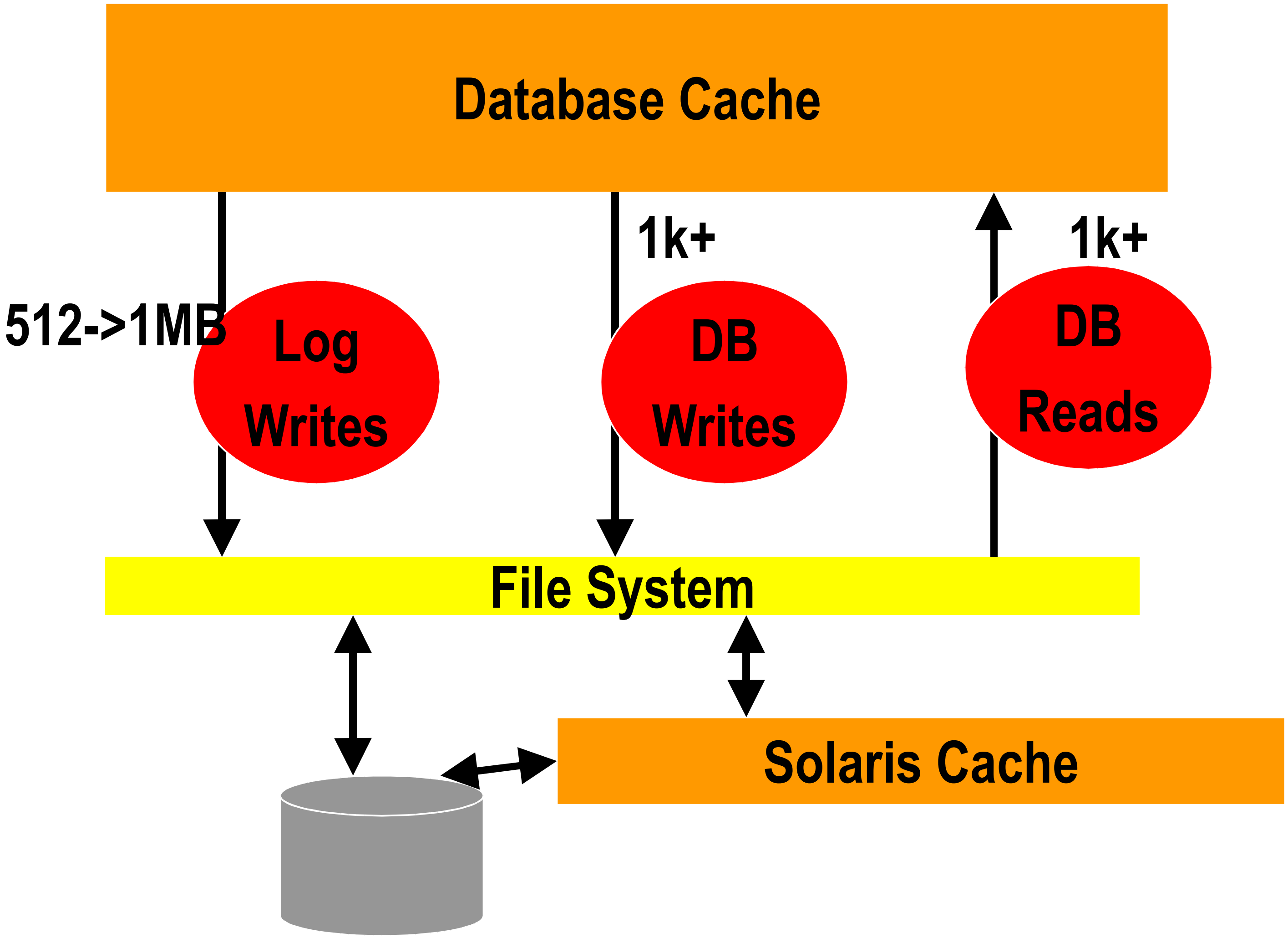
UFS Access times

- Access times are updated when file is accessed or modified
  - > e.g. A web server reading files will storm the disk with atime writes!
- Options allow atimes to be eliminated or deferred
  - > dfratime: defer atime write until write
  - > noatime: do not update access times, great for web servers and databases

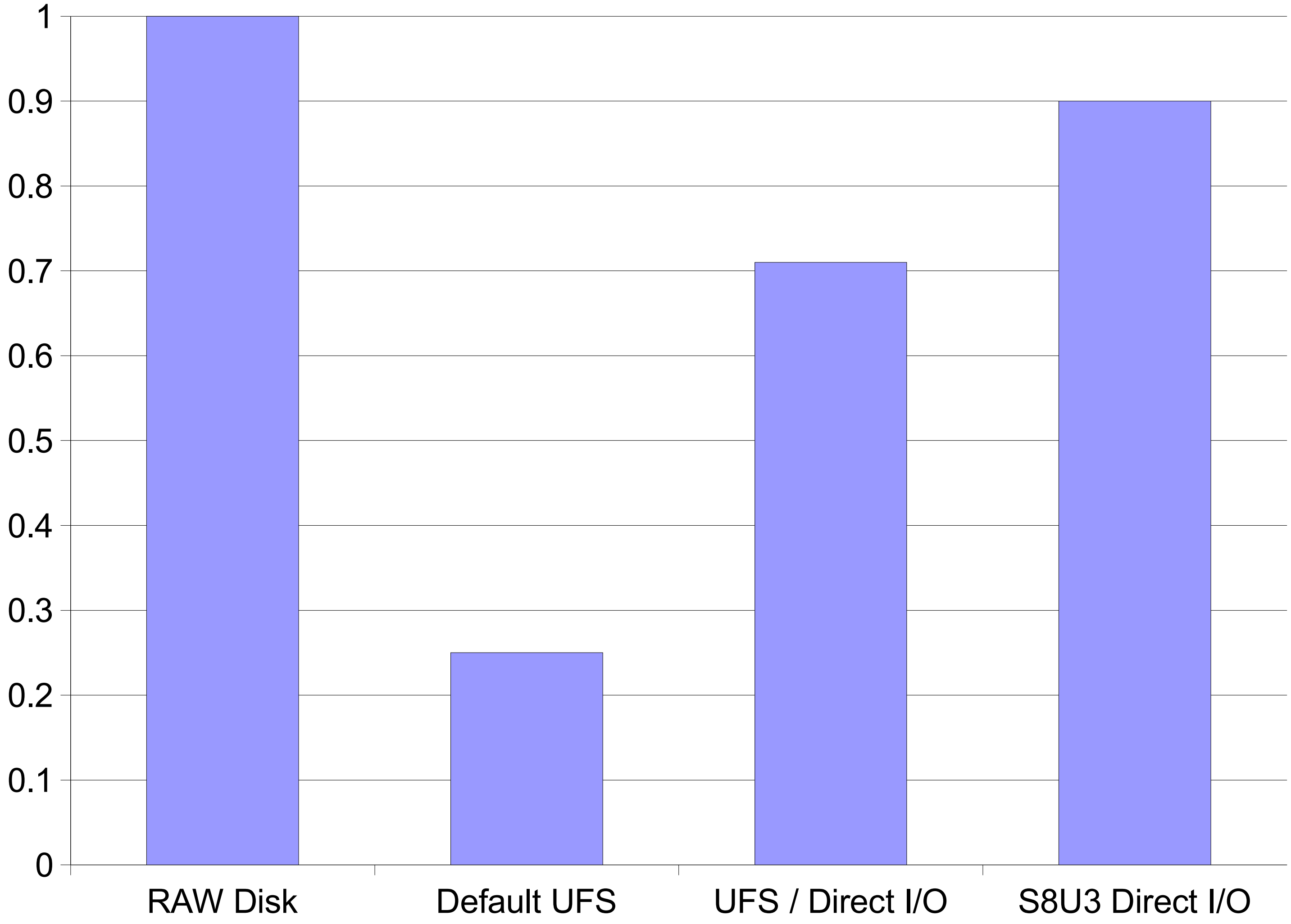
Asynchronous I/O

- An API for single-threaded process to launch multiple outstanding I/Os
  - > Multi-threaded programs could just just multiple threads
  - > Oracle databases use this extensively
  - > See aio_read(), aio_write() etc...
- Slightly different variants for RAW disk vs file system
  - > UFS, NFS etc: libaio creates lwp's to handle requests via standard pread/pwrite system calls
  - > RAW disk: I/Os are passed into kernel via kaio(), and then managed via task queues in the kernel
    - > Moderately faster than user-level LWP emulation

Putting it all together: Database File I/O



UFS is now Enhanced for Databases:



Key UFS Features

- Direct I/O
  - Solaris 2.6+
- Logging
  - Solaris 7+
- Async I/O
  - Oracle 7.x, -> 8.1.5 - Yes
  - 8.1.7, 9i - New Option
- Concurrent Write Direct I/O
  - Solaris 8, 2/01

Database big rules...

- Always put re-do logs on Direct I/O
- Cache as much as possible in the SGA
- Use 64-Bit RDBMS (Oracle 8.1.7+)
- Always use Asynch I/O
- Use Solaris 8 Concurrent Direct I/O
- Place as many tables as possible on Direct I/O, assuming SGA sized correct
- Place write-intensive tables on Direct I/O

Optimizing Sequential I/O File System Performance

Sequential I/O

- Disk performance fundamentals
  - Disk seek latency will dominate for random I/O
    - ~5ms per seek
  - A typical disk will do ~200 I/Os per second random I/O
  - 200 x 8k = 1.6MB/s
  - Seekless transfers are typically capable of ~50MB/s
    - Requires I/O sizes of 64k+
- Optimizing for sequential I/O
  - Maximizing I/O sizes
  - Eliminating seeks
  - Minimizing OS copies

Sequential I/O – Looking at disks via iostat

- Use iostat to determine average I/O size
  - > I/O size = kbytes/s divided by I/Os per second

```
# iostat -xnz
                    extended device statistics
    r/s    w/s   kr/s   kw/s wait actv wsvc_t asvc_t  %w  %b device
  687.8    0.0 38015.3    0.0  0.0  1.9    0.0    2.7   0 100 c0d0
```

- What is the I/O size in our example?
  - > 38015 / 687 = 56k
  - > Too small for best sequential performance!

Sequential I/O – Maximizing I/O Sizes

- Application
  - > Ensure application is issuing large writes
    - > 1MB is a good starting point
  - > truss or dtrace app
- File System
  - > Ensure file system groups I/Os and does read ahead
  - > A well tuned fs will group small app I/Os into large Physical I/Os
  - > e.g. UFS cluster size
- IO Framework
  - > Ensure large I/O's can pass though
  - > System param *maxphys* set largest I/O size
- Volume Manager
  - > md_maxphys for SVM, or equiv for Veritas
- SCSI or ATA drivers often set defaults to upper layers

Sequential on UFS

- Sequential mode is detected by 2 adjacent operations
  - e.g read 8k, read8k
- UFS uses “clusters” to group reads/write
  - UFS “maxcontig” param, units are 8k
  - Maxcontig becomes the I/O size for sequential
  - Cluster size defaults to 1MB on Sun FCAL
    - 56k on x86, 128k on SCSI
    - Auto-detected from SCSI driver's default
    - Set by default at newfs time (can be overridden)
  - e.g. Set cluster to 1MB for optimal sequential perf...
  - Check size with “mkfs -m”, set with “tunefs -a”

```
# mkfs -m /dev/dsk/c0d0s0
mkfs -F ufs -o nsect=63,ntrack=32,bsize=8192,fragsize=1024,cgsize=49,free=1,rps=60,
nbpi=8143,opt=t,apc=0,gap=0,nrpos=8,maxcontig=7,mtb=n /dev/dsk/c0d0s0 14680512

# tunefs -a 128 /dev/rdsk/...
```

Examining UFS Block Layout with filestat

```
# filestat /home/bigfile
Inodes per cyl group: 64
Inodes per block: 64
Cylinder Group no: 0
Cylinder Group blk: 64
File System Block Size: 8192
Device block size: 512
Number of device blocks: 204928

Start Block End Block   Length (Device Blocks)
----------- ----------- ----------------------
66272 ->    66463       192
66480 ->    99247       32768
1155904 ->  1188671     32768
1277392 ->  1310159     32768
1387552 ->  1420319     32768
1497712 ->  1530479     32768
1607872 ->  1640639     32768
1718016 ->  1725999     7984
1155872 ->  1155887     16
Number of extents:      9

Average extent size: 22769 Blocks


Note: The filestat command can be found on http://www.solarisinternals.com
```

Sequential on UFS

- Cluster Read
  - When sequential detected, read ahead entire cluster
  - Subsequent reads will hit in cache
  - Sequential blocks will not pollute cache by default
    - i.e. Sequential reads will be freed sooner
    - Sequential reads go to head of cachelist by default
    - Set system param *cache_read_ahead*=1 if all reads should be cached
- Cluster Write
  - When sequential detected, writes are deferred until cluster is full

UFS write throttle

- UFS will block when there are too many pending dirty pages
  - Application writes by default go to memory, and are written asynchronously
  - Throttle blocks to prevent filling memory with async. Writes
- Solaris 8 Defaults
  - Block when 384k of unwritten cache
    - Set *ufs_HW*=<bytes>
  - Resume when 256k of unwritten cache
    - Set *ufs_LW*=<bytes>
- Solaris 9+ Defaults
  - Block when >16MB of unwritten cache
  - Resume when <8MB of unwritten cache

Direct I/O

- Introduced in Solaris 2.6
- Bypasses page cache
  > Zero copy: DMA from controller to user buffer
- Eliminate any paging interaction
  > No 8k block size I/O restriction
  > I/Os can be any multiple of 512 bytes
  > Avoids write breakup of O_SYNC writes
- But
  > No caching! Avoid unless application caches
  > No read ahead – application must do it's own
- Works on multiple file systems
  > UFS, NFS, VxFS, QFS

Direct I/O

- Enabling direct I/O
  - Direct I/O is a global setting, per file or filesystem
  - Mount option

```
# mount -o forcedirectio /dev/dsk... /mnt
```

  - Library call

```
directio(fd, DIRECTIO_ON | DIRECTIO_OFF)
```

- Some applications can call directio(3c)
  - e.g. Oracle – see later slides

Enabling Direct I/O

- Monitoring Direct I/O via directiostat
  - See http://www.solarisinternals.com/tools

```
# directiostat 3
  lreads lwrites  preads pwrites     Krd      Kwr holdrds  nflush
       0       0       0       0       0        0       0       0
       0       0       0       0       0        0       0       0
       0       0       0       0       0        0       0       0
```

```
lreads = logical reads to the UFS via directio

lwrites = logical writes to the UFS via directio

preads = physical reads to media

pwrites = physical writes to media

Krd = kilobytes read

Kwr = kilobytes written

nflush = number of cached pages flushed
```

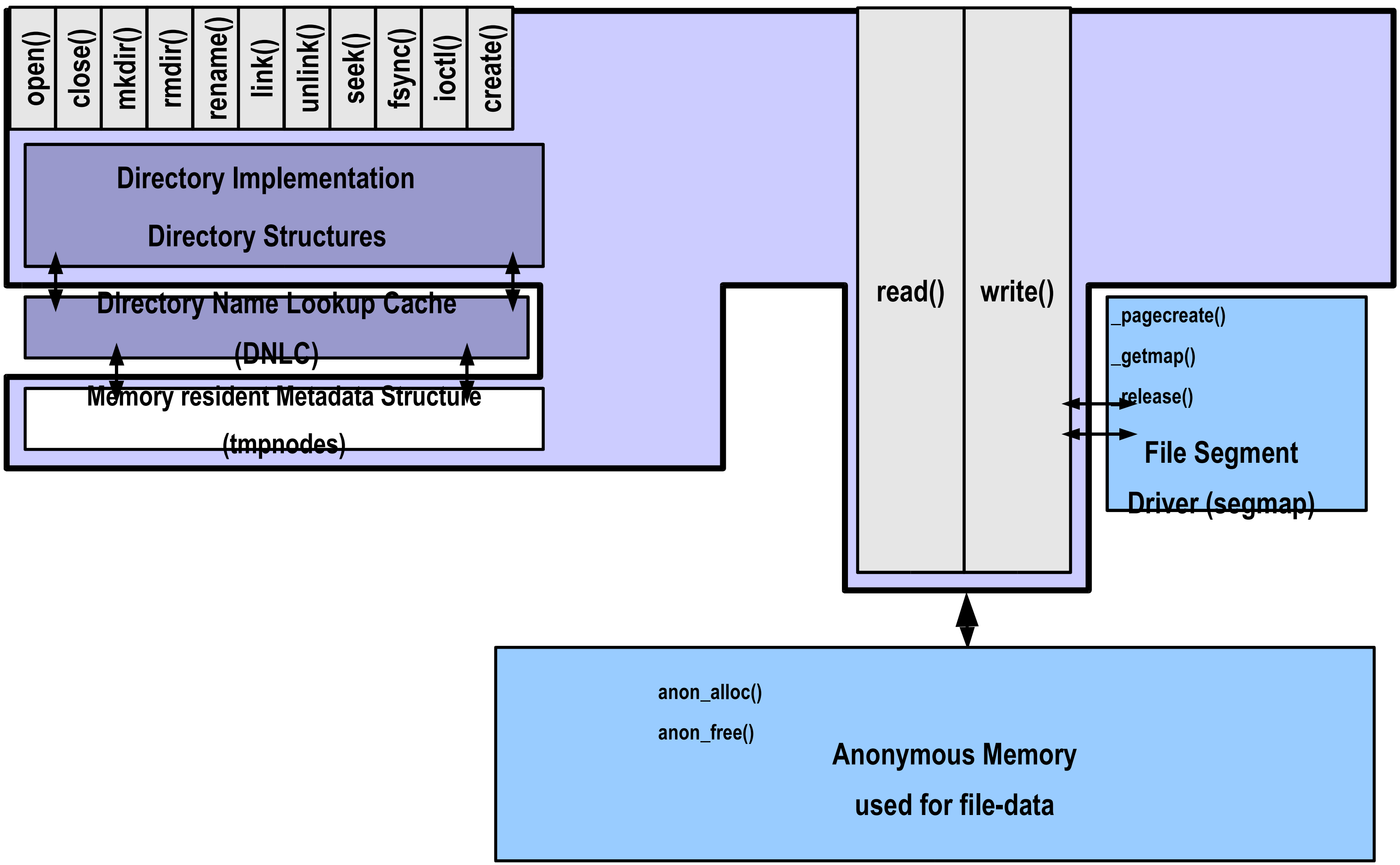
Using Direct I/O

- Enable per-mount point is the simplest option
- Remember, it's a system-wide setting
- Use sparingly, only applications which don't want caching will benefit
  - It disables caching, read ahead, write behind
  - e.g. Databases that have their own cache
  - e.g. Streaming high bandwidth in/out
- Check the side effects
  - Even though some applications can benefit, it may have side affects for others using the same files
    - e.g. Broken backup utils doing small I/O's will hurt due to lack of prefetch

The TMPFS filesystem: A mountable RAM-Disk

- A RAM-file system
  - The file system equivalent of a RAM-DISK
  - Uses anonymous memory for file contents and meta-data
- Mounted on /tmp by default
- Other mounts can be created
  - See mount_tmpfs
- Practical Properties
  - Creating files in tmpfs uses RAM just like a process
  - Uses swap just like a process's anonymous memory
  - Overcommit will cause anon paging
- Best Practices
  - Don't put large files in /tmp

TMPFS File System Architecture

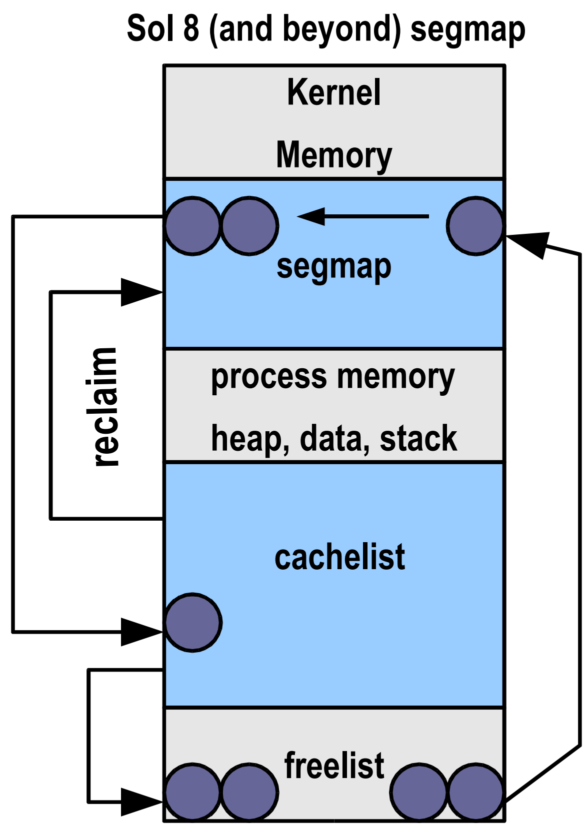


tmpfs

```
sol8# mount -F tmpfs swap /mnt
sol8# mkfile 100m /mnt/100m
sol9# mdb -k
> ::memstat
Page Summary                Pages                MB  %Tot
------------     ----------------  ----------------  ----
Kernel                      31592               123   12%
Anon                        59318               231   23%
Exec and libs               22786                89    9%
Page cache                  27626               107   11%
Free (cachelist)            77749               303   30%
Free (freelist)             38603               150   15%
Total                      257674              1006

sol8# umount /mnt
sol9# mdb -k
> ::memstat
Page Summary                Pages                MB  %Tot
------------     ----------------  ----------------  ----
Kernel                      31592               123   12%
Anon                        59311               231   23%
Exec and libs               22759                88    9%
Page cache                   2029                 7    1%
Free (cachelist)            77780               303   30%
Free (freelist)             64203               250   25%
Total                      257674              1006
```

The Solaris 8, 9 & 10 File System Cache



Tuning segmap

- By default, segmap is sized at 12% of physical memory
  > Effectively sets the minimum amount of file system cache on the system by caching in segmap over and above the dynamically-sized cachelist
- On Solaris 8/9
  > If the system memory is used primarily as a cache, cross calls (mpstat xcall) can be reduced by increasing the size of segmap via the system parameter segmap_percent (12 by default)
  > segmap_percent = 100 is like Solaris 7 without priority paging, and will cause a paging storm
  > Must keep segmap_percent at a reasonable value to prevent paging pressure on applications e.g. 50%

Tuning segmap_percent

- There are kstat statistics for segmap hit rates
  - Estimate hit rate as (get_reclaim+get_use) / getmap

```
# kstat -n segmap
module: unix                            instance: 0
name:   segmap                          class:    vm

        crtime                          17.299814595
        fault                           17361
        faulta                          0
        free                            0
        free_dirty                      0
        free_notfree                    0
        get_nofree                      0
        get_reclaim                     67404
        get_reuse                       0
        get_unused                      0
        get_use                         83
        getmap                          71177
        pagecreate                      757
        rel_abort                       0
        rel_async                       3073
        rel_dontneed                    3072
        rel_free                        616
```

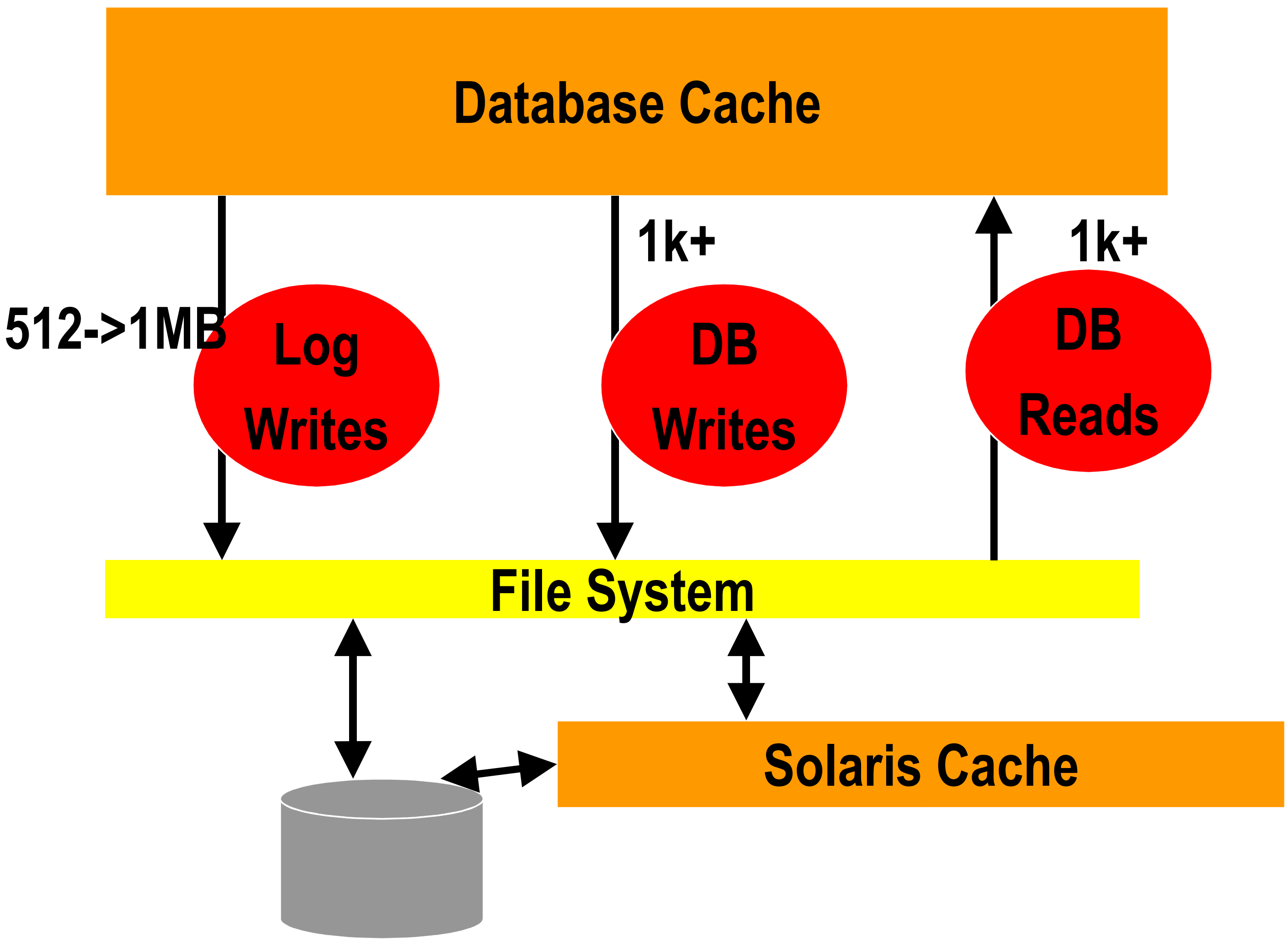
UFS Access times

- Access times are updated when file is accessed or modified
  - > e.g. A web server reading files will storm the disk with atime writes!
- Options allow atimes to be eliminated or deferred
  - > dfratime: defer atime write until write
  - > noatime: do not update access times, great for web servers and databases

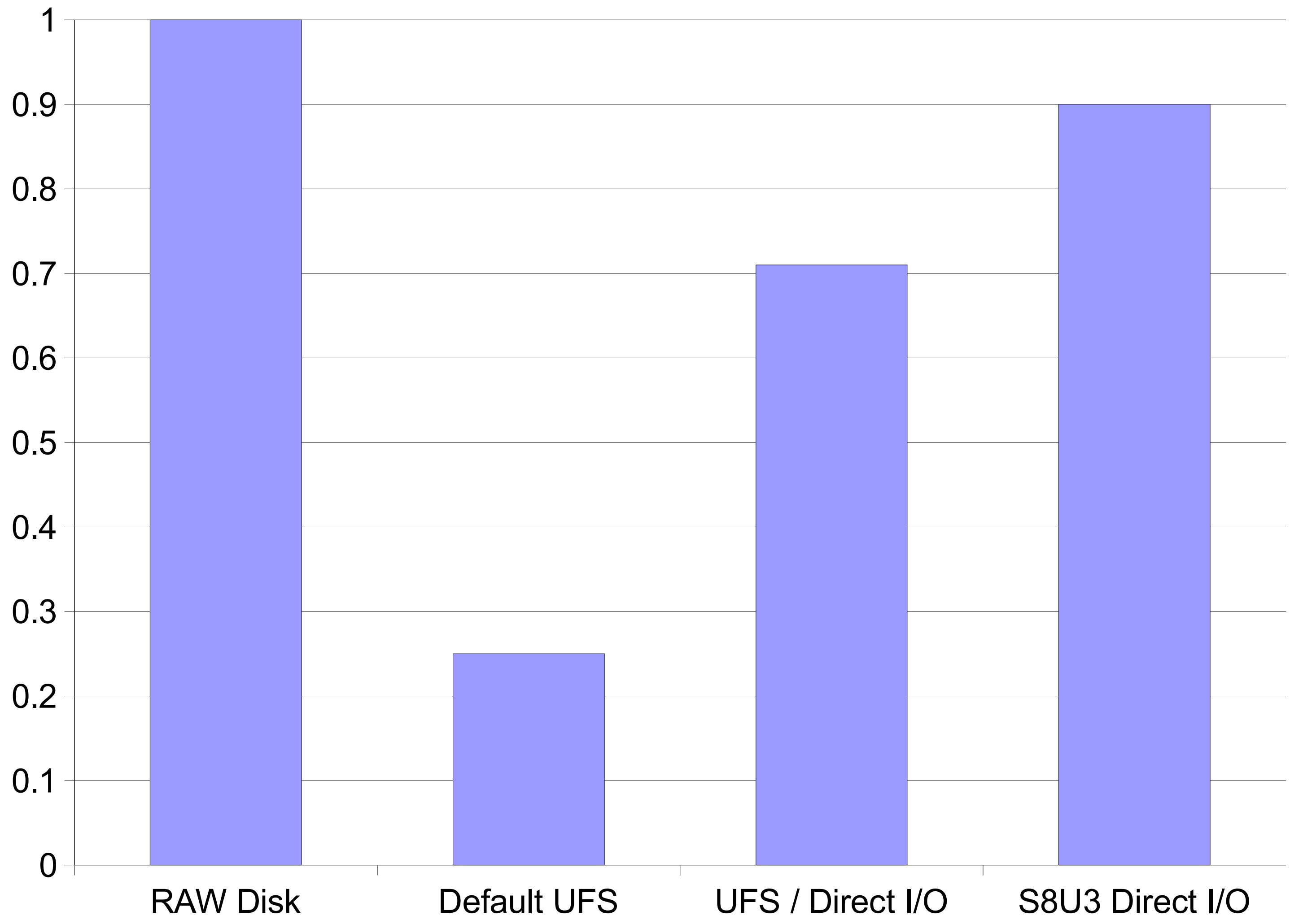
Asynchronous I/O

- An API for single-threaded process to launch multiple outstanding I/Os
  - Multi-threaded programs could just multiple threads
  - Oracle databases use this extensively
  - See aio_read(), aio_write() etc...
- Slightly different variants for RAW disk vs file system
  - UFS, NFS etc: libaio creates lwp's to handle requests via standard pread/pwrite system calls
  - RAW disk: I/Os are passed into kernel via kaio(), and then managed via task queues in the kernel
    - Moderately faster than user-level LWP emulation

Putting it all together: Database File I/O



UFS is now Enhanced for Databases:



Key UFS Features

- Direct I/O
  - Solaris 2.6+
- Logging
  - Solaris 7+
- Async I/O
  - Oracle 7.x, -> 8.1.5 - Yes
  - 8.1.7, 9i - New Option
- Concurrent Write Direct I/O
  - Solaris 8, 2/01

Database big rules...

- Always put re-do logs on Direct I/O
- Cache as much as possible in the SGA
- Use 64-Bit RDBMS (Oracle 8.1.7+)
- Always use Asynch I/O
- Use Solaris 8 Concurrent Direct I/O
- Place as many tables as possible on Direct I/O, assuming SGA sized correct
- Place write-intensive tables on Direct I/O

UFS write throttle

- UFS will block when there are too many pending dirty pages
  - > Application writes by default go to memory, and are written asynchronously
  - > Throttle blocks to prevent filling memory with async. Writes
- Solaris 8 Defaults
  - > Block when 384k of unwritten cache
    - > Set *ufs_HW*=<bytes>
  - > Resume when 256k of unwritten cache
    - > Set *ufs_LW*=<bytes>
- Solaris 9+ Defaults
  - > Block when >16MB of unwritten cache
  - > Resume when <8MB of unwritten cache

Other Items For Solaris UFS

- Solaris 8 Update 2/01
  - File system snapshots
  - Enhanced logging w/ Direct I/O
  - Concurrent Direct I/O
  - 90% of RAW disk performance
  - Enhanced directory lookup
  - File create times in large directories significantly improved
  - Creating file systems
    - Faster newfs(1M) (1TB was ~20 hous)
- Solaris 9
  - Scalable logging (for File Servers) 12/02
    - Postmark whitepaper
  - > 1TB file systems (16TB) 8/03

Solaris Volume Manager

- Solaris 9
  - > Integration with live upgrade 5/03
  - > >1TB Volumes 5/03
  - > >1TB Devices/EFI Support 11/03
  - > Dynamic Reconfiguration Support 11/03
- Future
  - > Cluster-ready Volume Manager
  - > Disk Set Migration: Import/Export
  - > Volume Creation Service

Volume Manager/FS Features

Feature	Solaris	VxVM	VxFS
Online Unmount	Yes		
Raid 0,1,5,1+0	Yes	Yes	
Logging/No FSCK	Sol 7		Yes
Soft Partitions	Sol 8	Yes	
Device Path Independence	Sol 8	Yes	
Database Performance	Sol 8 2/02		QuickIO
Integration with Install	Sol 9		
Multi-Pathing	Sol 9	Yes/DMP	
Grow Support	Sol 9	Yes	Yes
Fast Boot	Sol 9		
Integration with LU	Sol 9 5/03		
>1TB Volumes	Sol 9 5/03	3.5	
>1TB Filesystems	Sol 9 8/03		3.5/VxVM
>1TB Devices/EFI Support	Sol 9 8/03		
Dynamic Reconfiguration Integration	Sol 9 8/03		
Cluster Ready Volume Manager	Future	VxCVM	
Disk Group Migration: Import/Export	Future	Yes	

Summary

- Solaris continues to evolve in both performance and resource management innovations
- Observability tools and utilities continue to get better
- Resource management facilities providing for improved overall system utilization and SLA management

Resources

- **`http://www.solarisinternals.com`**
- **`http://www.sun.com/solaris`**
- **`http://www.sun.com/blueprints`**
- **`http://www.sun.com/bigadmin`**
- **`http://docs.sun.com`**
  - "What's New in the Solaris 10 Operating Environment"
- **`http://blogs.sun.com`**
- **`http://sun.com/solaris/fcc/lifecycle.html`**

Solaris 10
Performance, Observability & Debugging

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